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 (Alirezadeh, Osmun/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
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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, Jeanne 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 profited 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 Field, Bob Ford, Jim Goodridge, Dick Fields, Bob Roche of the Regional Water Quality Control Board, 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 Shultaf 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 Davidsen, Richard Dey, Robert Esra, Lindsay Green, Karla Heerman, Joseph Malin, Lola Mayes, and Jay Nations. 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 Davidsen, Richard Dey, Robert Esra, Lindsay Green, Karla Heerman, Joseph Malin, Lola Mayes, and Jay Nations. The photography that appears in the volume was made by Trailways and its staff led by George Rice & Sons.

From private firms, the project benefited from the efforts of: Mindy Skaim and Rusty Schweickart, assistants to Governor Brown; Richard Kharibian and Rusty Schweickart, assistants to Governor Brown; whose experience in developing atlases of their own in Oregon and Alaska helped us avoid many pitfalls; to James F. Collins 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 steer us through the thicket 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 Bremner, and Ralph Vicero of California State University; Northbridge; Lawrence J. Andrews and Kenneth Thompson of the University of California, Davis; Kent Stoddard, Ray Norman, and Karen Becker of the Office of Planning and Research; and John Balsch and Robert Brownlee of the Department of General Services. Very special thanks are due also to Jacques Bazraghi and Rusty Schweckart, assistants to Governor Brown, whose fine work 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. The role of water in the economic development of the American Southwest over the next ten years. And yet, at a time when water is crucial for the future, we have had few places to turn for a basic understanding of the critical, water-related questions 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, led by Dr. J. A. Johnson, and assembled as the basic data and detailed information for the preparation of maps from a wide range of local, state, and federal sources throughout the state. The 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 to our approach to its design. 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 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 that has been produced as a result of 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 the authors. They 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. 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.
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 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 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 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.

AFFUX WATER DEMAND. The quantity of water demanded in the purchase of some exclusive of any water lost in transport to that point.

AGENTS. 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 material is a confined aquifer.

ARTESIAN WELL. A well tapping an aquifer in which the water level will stand above the bottom if the seepage 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 called a spring.

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 use may vary with locality or custom, although the term is most frequently defined by statute or court decisions. The State Water Resources Control Board recognizes 21 beneficial uses of water and establishes the levels of water quality required for each.

ECONOMIC 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.

ECONOMY. 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.

ENDOSYN. A channel used to divert flows from a treatment plant or from a river or stream or river that is not attributable to runoff from rain or snow. Such a flow may be sustained by drainage from natural storage.

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

EFFECT. An artificial water channel supported on or above the ground for the conveyance of water in the same general direction as the flow, such as a canal, ditch, flume, or spillway which is used to control water flow.

EQUIVALENT. A graphic representation of some property of water which is displaced with respect to time.

EFFECT. A natural levee formed by the deposition of sediments 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.

EFFECT. 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 recognizes the exercise of 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 is in fact navigable at the time of California’s admission to the Union.

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

FLOWS. The movement of water through the intertices of soil at rank.

FLOWS. Any discernable, continuous 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.

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

FLOWS. The portion of the cost of developing and distributing a water supply which the water users are held responsible to repay.

FLOWS. 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.

FLOWS. 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.

FLOWS. As applied to groundwater, the maximum quantity of water that can be continuously withdrawn from a groundwater basins 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.

FLOWS. The setting of solids in any body of water because of gravity or chemical precipitation.

FLOWS. A creek or a meandering or tidal flat or an inlet from a river.

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

FLOWS. 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 economy. Usable storage capacity, however, is the amount of water of acceptable quality that can be economically developed 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.

FLOWS. The quantity of minerals in solution in water, usually stated in equivalent parts per million (ppm) or milligrams per liter (mg/l).

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

FLOWS. 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.

FLOWS. 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.

FLOWS. Any structure across a water source used to control, raise, or measure flows.

FLOWS. 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.

FLOWS. As applied to water and power, to provide the State Water Resources Control Board, or any other agency’s conveyance facilities for the purpose of transporting another agency’s supply.

Metric Conversion Factors

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CHAPTER 1

California's Water in Context

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 600 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 500 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 1,200 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 2,300 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, 2.3 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 2,000,000 gallons of water which 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 2,000,000 gallons 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 requires the equivalent of over 2,000,000 gallons of water.
Arrows mark paths of moisture inflow for storms producing large amounts of precipitation.

Green tint indicates areas receiving 24 or more inches of precipitation.

Arrows show approximate direction of inflow.

Scale: 1:10,000,000

California In Context
Population and Water Use

<table>
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<tr>
<th>State</th>
<th>A</th>
<th>B</th>
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Selected Western Rivers

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Selected Western Reservoirs

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California Surface Inflows & Outflows

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<thead>
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<th>Category</th>
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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 equivalent to only 31 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 development. 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 average 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-third 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 3.2 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 dry year 1977, however, groundwater provided about 80 percent of agriculture's needs when 20,000 new wells were drilled in this valley alone. Statewide, more than 30,000 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. In the future years, if the current trend continues, the overdraft will increase energy requirements for pumping, decrease water availability, procer 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 be predicted. But the situation clearly calls for increased sensitivity 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 uncontrollable 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 study that follow treat many of the factors and their interrelationships in detail. Only through enlightened public understanding of these complex issues can we hope to integrate divergent viewpoints and continue conversations 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 achievements to achieve a balance between water supply and water demand.
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 siltiferous 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 Sequoia 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 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 coast redwood and yellow 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 its 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 alpine community that is found throughout the Sierra; and the snow margin community of high alpine species 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 sticktack, 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 harshest 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.

**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

Histograms of mean monthly precipitation at representative stations refer to locations (with elevations) shown on map.
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 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 high pressure cells 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.

Precipitation includes all forms of water that fall from the skies. Water vapor in 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 in the Coastal Plain, and 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 successes of several years when precipitation was below the long-term average, perhaps interrupted by one 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, “cyclical” 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 to the earth’s surface from 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 evaporation 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 surfacess 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 effective 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-trending curves while dry periods of below-average precipitation produce downward-trending curves. These graphs show that wet and dry periods are variable in length and are not consistent 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.

San Joaquin

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

San Francisco Bay and Central Coast

- Russian River (16)
- Napa River (11)
- Coyote Creek (12)
- Salinas River (13)
- Arroyo Seco (14)

North Coast

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

Lahontan

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

North Coast

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

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Lahontan

- Truckee River (24)
- East Fork Carson River (25)
- East Walker River (26)
- Owens River (27)
- Salt Creek (28)
The dramatic contrast between the volumes of water supplied by precipitation in the South 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 runoff is less in the South Coast as compared to the much larger volumes of water carried in the upper Sacramento River. Thus the graphic presentation of annual runoff and seasonality in this south section shows the great difference that exists between the seasons of the rivers and the seasons of the heavens, as the time-delays 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 "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, 65,000 cfs in the San Diego 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 during 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. Most of it, its 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. Today, however, Owens Lake and its tributaries are no longer fed by the rivers in Indian Wells, Searles, Panamint, and Death Valley. But that was during the Ice Age which ended thousands of years ago. The Owens River has lived down to its redwood stage of its alluvial history—a fossil river system—are the high shore lines in Death Valley and Panamint Valley, and the briny, hot and salt lake that has accumulated in Searles Lake.

The southern part of the Central Valley is currently a closed basin. On April 1, Vista Grande was the ultimate goal of the Kern River, southermost of the Sierra rivers. Two smaller rivers, the Tule and Kaweah, flow toward the Kern that farther north called Tulare Lake, and the Kings River still farther north turns southwest 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 overflowed 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 40 inches, and 10 to 20 percent of this becomes the mean annual runoff. Exceptionally high rainfall and runoff are recorded in some places: the 60-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 Lyle 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 rainfall precipitation to provide a water surplus in a normal year. The rivers flowing westward have mean annual precipitation ranging from 20 to 30 inches, of which 40 to 65 percent becomes runoff. The streams draining the east slopes of the Coast Ranges 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 brought by snowmelt to the 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 part of California north of Lake Tahoe and east of the Sierra Nevada has mean annual precipitation ranging from 20 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 serving itself from the Sacramento River system because of water deficiency, and several alkali lakes farther south near the Nevada border. It is also lave 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 plateaus 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 groundwater movement from adjacent mountains. 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 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 coastal redwood tree survive long rainless periods partly by interception of atmospheric water, particularly in the humid coastal areas. Like the individual cold rock outcrop in the high mountains of California intercept atmospheric water, but they do it in a big way. All winter long those mountains receive and accumulate snow, and 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 rainy 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 sand and 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 with depth. As the infiltration becomes more difficult, the water collects in depressions in the land surface, and these provide estimates of the natural storage of water that will contribute to freshets in the forthcoming rainy season.

Some groundwater is retained as soil moisture in the unwatered 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 dormant in early spring, and become golden fire-hazards in summer. Similarly, the first rains of winter reduce the summer pool of heat and increased soil moisture revitalizes the forests, chaparral, and brush lands. For much of California's native vegetation, summer is consequently the dry 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, which by plants in California have adapted to summer drought conditions. Some plants have adapted to drought conditions by shedding small leaves to reduce the evaporative surface, or leaves that orient side ways to the sun in order to
Average Snow Depth and Water Content

Snow Depth at Donner Summit

Snowfall Incidence in the Central Sierra
and desert vegetation responding to a rainstorm responding to a rainstorm. 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.

North Palisades Glacier, a remnant of the great mass of ice which covered the face of California, appears as the darkest deep blue portion of the ice cap visible in the upper 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.

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 movements are chiefly upward and downward, and not across property lines. Each man has a God-given right (Matthews 3:43) 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 streamborne 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 sufficient 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 underly ing 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 rainy 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 is 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 34 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 9,100 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 primarily 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 the availability of soil moisture decreases, the combined rate of potential and actual evapotranspiration increases and deficits consequently occur. When soil moisture is replenished and the natural demands of evapotranspiration are satisfied, as in the months of January and February at Sacramento, surplus moisture may percolate downward as groundwater or move horizontally as runoff.
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 winter rain and it has a perennial outflow which is today regulated.

Geology. Clear Lake, on the northeast corner of California, is a shallow lake but has been subject to several droughts, but overflows southward into the North Fork of the Pit River in wetter years. This has not occurred, however, since the middle of the last 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 a residual lake 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 northward 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. Ritba 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 a similarly dry area in the San Joaquin Valley. Rosamond Lake, also in Antelope Valley, and Soda Lake, which sometimes has water, are larger than the Orrovile 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 1846 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 the average 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."

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 1962, 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 seawater 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.
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...
The map on the facing page displays the natural configuration of lakes, rivers, and related vegetation as it existed prior to the advent of European and Anglo-American settlers upon their arrival in California. Urban and agricultural development have taken a toll on the landscape, although some areas of the state remain largely unexplored.

The 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 have fluctuated from year to year, and the map itself was 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.

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 California 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 devastation 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 miners into large enterprises. In 1860, 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 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 rule 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 valley farmers were still subject to frequent and disastrous flooding.

The progress of hydraulic mining, in the Sierra Nevada brought the first major post-mine-muck-filled alterations in the natural watersheds. In the photo below, water levels in the upper Tejon Creek are seen to be rising behind the levees which are rapidly being extended.

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 flatterns 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, $500,000 was spent on levees and dikes with little success.

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, these became poisons almost as soon as hydraulic mining began, the riverbeds had in fact been filling in for some years.
The Virgin Waterscape

- Lake: Estimated natural shorelines.
- Freshwater Marsh: Land inundated annually and populated by tulips, cattails, or other hydrophytic vegetation.
- Riparian Forest: Broadleaf deciduous forest growing naturally on the sides or banks of rivers and streams, and in bottomlands.
- Coastal Brackish Marsh: Land inundated alternately by saline water and fresh water.
- Coastal Salt Marsh: Land along the upper intertidal zone of protected shallow bays, estuaries, and coastal lagoons. Salt-tolerant plants predominate.
- Saline and Alkaline Lands: Sinks and basin rim lands characterized by intermittent water high in mineral content.
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

Flow Past the Latitude of Sacramento During Flood Event

- Yolo Bypass near Lisbon
- Flow in the Absence of Regulation
- Sacramento River at Sacramento

Maximum/Minimum Discharge

- Sacramento River at Red Bluff
  - Highest Mean Daily Discharge
  - Lowest Mean Daily Discharge
- Sacramento River at Yuba
  - Highest Mean Daily Discharge
  - Lowest Mean Daily 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 floodwater storage.
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 sand and mud 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 mountains.

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 confine 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 deposition. Flood control, navigation, and recreation 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 Wiegand v. Nist, Kress & Co., by assuring 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.

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 resolution of the Sacramento River's continuing flood control problems.

The involvement of the federal government in California water affairs began as early as 1860, 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 1875 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 constructing 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 drainaways 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 1902, 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 flood-time 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 1906, 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 400,000 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 leved 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
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 acting 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.

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grown to a city of almost 50,000 persons, the state's 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 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 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 main water (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 exclu-
sive 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 main 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 pueblo did both an incontestable right to water and a political organization for its distribution exist. As a result, only there were water development con-
tinued 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.

Los Angeles' water colony endured 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 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 neces-
sary 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, 35,502 acres of Rancho delSan 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-
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 Cajó 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 26 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 44-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 interest 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.

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 doused by the Civil War. He worked instead as a field engineer, draftsman, and hydrographer for the Army Corps of Engineers, and his experience in this connection of the sand dunes south of Lands End in San Francisco led to his appointment as assistant 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 1875, Governor William Irwin appointed Hall to head the newly created Office of the State Engineer, which was charged with the responsibility for determining the extent of debris damage and developing a program of relief. Hall’s work on the problem of debris 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 1889 to 1899 he served as a consulting engineer for the mines of South Africa, and in 1899 he developed a series of reports on irrigation and reclamation 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 wishes of the United States Department of the Interior that the Hetch Hetchy system be entirely public. After two years of bickering over price, Hall ultimately sold the holdings he had acquired for approximately $300,000 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 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 Cal¬ifornia Central Railroad’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.
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 colonists clients. And, once the lands had been sold, the canal owners often attempted to maintain high profits by exercising their monop- lonic 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, began as early as 1858. Following enactment of the Green Act in 1868, these efforts were greatly expanded. The water was easily 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 traycer 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 downstram appropriators of the Kings' flow. The owners of a large ranch in the Kings delta, the Laguna de Tule, initiated no less than 135 lawsuits against upstream irrigation companies to protect their claim to an undiminished flow of the river through the rancher's lands. At the heart of these and similar conflicts throughout the state lay a series of important questions about the meaning and validity of the system of riparian water rights, which was part of the English common law adopted by the State Legislature in 1850 as the basic legal system for California.

THE CONFLICT OVER RIGHTS

The word rival is derived from the Latin word rivus, 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 word water, or more precisely water rights is consequently in large part a history of the conflict between irrigators and the Riverside Canal 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.

The appropriative doctrine was first applied in the California Constitution of 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 have the right to the waters of the stream for use on those adjoining lands to the exclusion of other users. 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 appropriative rights. Under this doctrine, the right to water is awarded to the first person who puts it 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.
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 pri-
ivate 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 those 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 par-
ticular, 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, Con-
gress 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 do-
main was recognized. Indeed, the ultimate contro-
versy 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 consid-
erable weight. Second, as mining decreased in
importance in California and agricultural activity
increased, and as a larger and larger portion of Cali-
forinia land was transferred to private ownership, the
practical consequences of the riparian doctrine grew
more obvious. In terms of the number of acres af-
fected, the doctrine constituted an increasingly sig-
ificant barrier to any land development dependent
on appropriation. In addition, the decision by Colo-
rado and other western states in the years after Cro-
dall v. Woods to opt for the impetus to development,
stability, and flexibility which the appropriation doc-
trine offered, spurred efforts in California for a re-
examination of the early California decisions.

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 areas on the
map indicate irrigated lands in 1866; the green areas identify
swimming and bottom lands, and the vast fields of pink
mark the lands that Hall argued might someday be developed for
irrigation through the reconstruc-
tion of irrigation systems.
irrigation in the same light that eastern people generally view it, i.e. 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 the 1920s. The federal investigators who prepared the report attributed this prejudice against irrigation in part to a fear that it would spread malaria and 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 book 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, 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 from that period with a dog-in-the-manger principle whereby a riparian owner could obtain a basic injunctive right against any 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 determining his right to water, thus critics of a 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, in the case of Horninghaus v. Southern California Edison Company, held that the use of water by riparian right forecloses any constitutional right to an appropriation of water even though the riparian owner himself was not using it. The Court ruled that the riparian owner's rights were absolute; no higher use could be made of the water. 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.

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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 government 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 78 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 produce, 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 Oil West magazines were founded to promote the Mediterranean qualities of the Southern California climate and, in keeping with this theme, town sprang up names like Hesperia, Tarzana, Terrace, and Verona, while San Diego and Long Beach tossed 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 1860s 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 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 26 cities in the United States in 1860, San Francisco was one of only four that still lacked a municipally owned water system. Los Angeles stood still further afield 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 politics. As one Los Angeles city councilman remarked as he prepared to sign over the city's water rights in 1866, "It is well known by past experience that cities and towns can never manage enterprises of that nature as economically as individuals, 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 of 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 substantial 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
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 85 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 irrigation rights. The Tuolumne River provides 80 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.

Aqueduct Systems

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 medium type are reported values. medium type represents inferred values. Dashed paths represent no flow in fiscal year 1975.
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 states 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 1906 San Francisco's per capita water consumption would exceed one hundred gallons a day, whereas they favored a level of 70 to 130 gallons a day (a level not actually reached until the 1960s). They also promoted the project with the idea that it would eliminate or substantially reduce ground seepage and prevent typhoid epidemics, feats which they claimed would mitigate the city's seasonal water shortages. In 1908, San Francisco voters supported the project with a $600,000 bond issue and the city's attorney set about acquiring rights of way for the small dam a few miles south of the town of Groveland, which some thought it a little too soon when the city announced it had run out of water for the construction of transmission lines just as the project reached its final transmission facilities in Newark. 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 the power, it then sold it for $9 million, and long-time supporters of the project had long since paid off its costs. San Francisco's city voters, however, refused to buyout PG&E's district. 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 1930, the city began the development of additional storage and power-generating facilities in the Cherry Valley. 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 project, a half mile 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:...
WILLIAM MULHOLLAND

When asked once in court to describe his qualifications as an expert in water engineering, William McLeod 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.

Born in 1855, Mulholland landed in New York in 1874 as a journeyman tailor. 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 went down about six hundred feet we struck a rock," 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 LeConte'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 distrust 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 continued the confidence the public had placed in his abilities. To the progressive reformers of the period, Mulholland stood "as an example of what the application of science can do for his state when he holds his brief in court to describe his qualifications as an expert in water engineering."

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.

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 the Owens Valley 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 1920 and 1930, 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 irrigation project which would have doubled the acreage then in agricultural production within the valley. When Los Angeles declared its own interest in the area, 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 340,000 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 Owens Valley. Inyo. Since the 1930s, Los Angeles has exercised its control over more than 340,000 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.

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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 60 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 its 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 the 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 5,100 square-mile service area.

### MWD Operations, 1974/1975

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*Includes deliveries by MWD of Orange County.
*Includes all the water the City of Los Angeles is entitled to receive, but does not include water used by Los Angeles City agencies.
*Includes all the water used by Southern California Edison, Southern California Gas Co., and other Southern California Urban Delivery Systems agencies.
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 farther 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 dispute between California and Arizona, the city, in 1964, began construction of a second, smaller aqueduct, paralleling the first, which is designed to carry up to 1.2 million acre-feet of water a year 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 supply of water to the 1.2 million 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.

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 it could currently exercise only 30 percent of the 1.2 million acre-feet of water its aqueduct supplies 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 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 and water developed in the Owens Valley, which 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 delivered, Los Angeles taxpayers paid a cumulative total of $335 million in property taxes to maintain the city's right of access to MWD's supplies 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 1975-77, 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 contrast 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 how much water could be gained through public water development. Its water projects today reach out hundreds of miles across the State to areas which, before the city's decision to build the Metropolitan Water District, were remote and financially isolated, and to whose residents the city's water brought new economic opportunities. The city 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, through the development of roads, fish hatcheries, hydroelectric power generated along the city's gravity system, Los Angeles today derives 80 percent of its water from MWD's supplies, or $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.

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In 1921, 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.
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 1,900-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 sometime Indian agent, Dr. Oliver M. Wozencraft, first conceived of irrigating the Imperial Valley with a gravity-fed canal from the Colorado where he passed through the area on his way to the gold fields in 1849. His scheme founded, 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 1,400 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 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 Indian century advocates of systematic irrigation such as John Wesley Powell, second director of the United States Geological Survey, no serious efforts had ever been 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 H. Chaffey had 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 bars 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 years, 400 miles of canals and laterals had been built and more than 120,000 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 was flowing through Mexico for 80 miles before turning back north again to the United States, Rockwood had promised to provide half the water diverted from 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 silting 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 headgatem. 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 junction with the Colorado. In a matter of weeks, most of the 10,000 acre Sinf 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 13,000 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 be 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.

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 to report on the stream's capacity to support "a large and prosperous population." "We have in the Colorado an Egyptian Nile awaiting regulation," declared Joseph B. Lippincott, one of the pioneers in western reclamation, "and it should be treated in an intelligent and vigorous 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, Los Angeles was 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 McMillan, chief of the Bureau of Water Works and Supply, that the Buchanan, 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. But a new dependence on the Colorado 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

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

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 1868, 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 Riverdale Colony in 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 1883 for Chaffey to bring his systems to California with posters like the one above.

In 1885 Chaffey arrived in California with Charles Rockwood, a developer with which his name would be most enduringly linked in California history, the development of the Imperial Valley. Chaffey's idea as a master promoter, in fact, stems, in some form at least, from Rockwood's 1887 offer of $3 million to the Los Angeles City of Los Angeles. As early as 1877, the city's water planners were interested in developing 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

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Growing Season Evapotranspiration

Each isometric graph displays crop evapotranspiration, measured in inches per month, during the growing season within each of ten distinct regions.
She has always been inimical to the interests of the obtain electric power "direct from the Colorado 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 kilowatt-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 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. Since the river, California had early aroused concern as to its respective water rights. Of the states in the basin, California 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 uninvolved. Her topography was such that she sought only a small volume of water, and Arizona and California readily agreed to her requests.

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 uninvolved. 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 unappropriated 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 undertake 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 next page shows the amount of water required 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 Colorado River water. In the photograph above, the Salton Sea and Imperial Valley can be seen sloping 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.

THE METROPOLITAN WATER DISTRICT

The Metropolitan Water District today is a wholesaler of water to cities and water districts serving 11 million people over 4,500-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 in 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 if it joined the MWD in 1949. Rather than pay these high and ever-increased 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 1947 the district delivered only 16,000 of the 400,000 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 additions 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 1937, San Diego led the formation of the League of the Southwest to promote the Boulder Canyon Project as the means to make San Diego a major port and industrial center. Although Los Angeles’ decision in 1923 to seek Colorado water for itself doused 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 1941 onward, San Diego in 1945 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 member agencies 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 1948. Despite these problems, however, MWD pressed ahead in 1952 with a $200 million expansion program to bring its undersized 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 1985.

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 1930 from 50 percent to only about 25 percent, the city still commands almost twice as many votes as any other single member. By voting 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.

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 plains. The next year, the All-American Canal commence 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 3.5 million inhabitants to about three million. Other communities registered even greater growth rates, and new cities sprang up where 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 which, in 1940, was only 112,000 acre-feet of Colorado River water and this right defined by the different land uses which an abundant water supply makes possible.

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 vs. California apportioned 4.4 million acre-feet to California of the first 7.5 million acre-feet per year available for consumptive use plus 80 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’s 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 the city will need to receive all the way 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 70 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, and for example, only 12,156 acres were under irrigation as of 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 Valley, where crops and livestock production that year were valued at more than half a billion dollars.

The greatest 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 valleys. 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

vanishing.
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 the heart of the...
This map displays the amounts of water used for various purposes in each of the seven states of the Colorado River Basin and Nevada during calendar year 1975. The water is obtained from the mainstream of the Colorado River, its tributaries, and the groundwater basin. The map also details the location of major Indian reservations, the quality of flows at key tributary junctions, and the reservoirs.

### Consumptive Uses and Losses (1,000 Acre-Feet)

- Irrigated Agriculture: 276.1
- Municipal and Industrial: 94.7
- Undifferentiated Exports: 20.3
- Reservoir Evaporation: 438.2
- Total Consumption and Losses: 842.0
- Main Stem Reservoir Evaporation and Channel Losses: 12.9

### Apportionments

- Upper Basin: 371.3
- Lower Basin: 429.7
- Mexico: 70.0

### Water Quality

- Concentrations are measured in parts per million of total dissolved solids. The data have been related to flows in order to express mean annual flow-weighted levels of concentration for 1975.

### Virgin Flow at Lee Ferry

- (millions of acre-feet)

### Regions

- **Upper Basin**
  - Nevada
  - Utah
  - Colorado
- **Lower Basin**
  - California
  - Arizona
  - New Mexico

### Aqueducts and Pumping Plants

- **Virgin Flow at Lee Ferry**
  - (millions of acre-feet)

### Indian Reservations

- **Aqueducts and Pumping Plants**

### Significant Locations

- Las Vegas
- Flagstaff
- Phoenix
- El Centro
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 870,000 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 states most commonly used are the Upper Basin states, will not be able to use more than 5,800,000 acre-feet per year. The Upper Colorado River Basin Compact apportioned 80,000 acre-feet per year to Arizona and the remainder of each state’s apportionment for the Lower Basin. The upper Basin states, in their tributaries, are apportioned 50 percent of any surplus water to California, 44 percent of mainstream water and thereby, assure sufficient acre-feet available in the mainstream for the lower Basin for consumptive use by the three Lower Basin states as follows: Arizona 2.8, California 4.4, and Nevada 300,000. If more than 5.7 million acre-feet are available, then California is apportioned 20 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 water rights, and if the amount the remaining to the states. The 1928 Colorado River Basin Project Act gave California’s apportionment of 4.4 million acre-feet per year over the Central Arizona Project. Streamflow from the tributaries in the Lower Basin have not been apportioned by compact or adjudicated among the states. For the Upper Basin states, the total water use shown on the map for Colorado River water, has been apportioned to 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 tributary states 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 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 shortage was an excess of the induced water 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.

The outcome of Indian claims and their impact on Southern California’s water uses will not be known for years. Southern California 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 these 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. 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 be eight times the expected losses of Colorado River water and thus help to meet the needs that will be created with expected increases in population. The water being brought southward, as events in 1977 indicated, can be diverted from the Colorado, even if water shortages will occur unless alternative sources are discovered or patterns of consumption altered. The Southwest water shortage, as events in 1977 indicated, can be shut down when drought hits the state. Statistics that 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.

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.
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, how-
ever, 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 districts 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 $200 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 thegrim 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 colonists established in 1908, was the first to draw its water by pumping from the lower San Joaquin River in Stanislaus County. Groundwater resources 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 of 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 Allensport San Joaquin and Kings River Canal Company with its 300 miles of canal sold water to subdivisions for less than two dollars an acre.

Doubtlessly the most successful colonies in the Central Valley, however, were those whose promoters 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 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. After irrigation, 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 especially 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 became a major feature of the Delta.

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 speculative inflated land prices were but the starting point for a small farmer's costs; to these 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 meet his initial outlay, and even more if he were selling colony real estate. The custo

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.
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 the water contractor from October 1974 through September 1975.

Water Contracting (Contracts/Cases/Acre-Feet)

- Mono x 1 to 1
- Orland WAA to 207,780
- Mono x 2 to 207,780
- Centre Coles WM to 70,177
- Hospital MO to 21,566
- W. Stenbret ID to 30,100
- Mono x 3 to 200,610

Central Valley Project Project—acqueduct/Canal

- Lake or Reservoir and ID for graph
- Pumping Plant and ID for graph
- River Plant and ID for graph
- Contractor's location

Facilities

Contract IDs:

- Del Monte
- North and South
- San Joaquin
- Coles
- Delta
- Carquinez
- Orland
- San Joaquin
- Modesto
- Amador
- San Luis
- Tracy
- O'Fallon
- Stockton
- Auburn
- San Joaquin
- Stockton

Energy Generation, Use, and Water Pumped

- Total energy pumped
- Energy generated
- Energy consumed

Reservoir Capacities

- Water storage capacity

* Mono represents the total number of water contracts (i.e. if that received 20,000acre feet in less than that stated during the water year. The numerical figure represents the total amount delivered collectively in all contracts.*
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 vexing obstacle. Supporters of the Marshall Plan in the Legislature set out to work implementing it through a proposed California Water and Power Act which would have provided for state distribution of all power generated by government-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 ownership 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 what he termed 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, $700 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 negotiable bonds for federal construction and operation. The first acceptance of some federal responsibility for implementing the Central Valley Project was in 1936 when the state supplemental 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 Delta-Mendota Project, in 1937. It was a 75-mile-long channel in the Golden State that the project which had come from California's water resources and water boards would be built at the same rate of speed the Bureau completed Hoover Dam. Development of the Central Valley Project was thus proved to cost for 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 operation 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.

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, sapping a triumphant engineering achievement in the Central Valley interbasin transfer system. The key structure was the massive 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 Keowee 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 Friant-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 was then represented as sufficient to meet the demands of industrial and agricultural interests which had been troubled during the 1920s with salt-water intrusion. The Delta's variability and extreme salinity were solved by 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 officials to use the project 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 sounding 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 the interests of farmers with competing water demands of industrial and agricultural interests which might intrude upon its power and irrigation 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 pointed out that California farmers, marketing practices so that the family farm provision of reclamation law could be enforced.

A resolution of the federal/state conflict was forged 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 farm community in the upper San Joaquin Valley were apprehensive over the stringing of the Bureau to expand its public power facilities with new transmission lines as they were 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 excised. 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 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 entire system and instead had only a land formula for the construction of its own project it would not build its own distribution system. And although PG&E through its allies in California's agricultural interests expropriated appropriations for the development of government-owned transmission lines while construction on the project went forward, it was not until the 1951 when the so-called wheeling agreement of that year, power
The reclaimed areas in the photographs above have been turned into richly productive croplands through the development of the modern water system. California and the facility of the California Water Project and Central Valley Project are at the lower left and San Joaquin River is at the upper right corner.

**THE 160-ACRE LIMITATION**

Few legislative acts have had an enduring 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 holdings 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.... One person as a whole will profit, for successful homesteading is but another name for the up-holding 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 landowners 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 to 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 meeting 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.

### Landowners in a Question that Remains before the Courts Today

As the agency responsible for enforcement of the 160-acre limitations, 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 controversy over the 160-acre limitation ranged with greater intensity. Of the 16,807,000 acres subject to the excess lands provision in all Bureau of Reclamation projects throughout the United States in 1977, fully 4,697,051 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.

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Landowners in a question that remains before the courts today. As the agency responsible for enforcement of the 160-acre limitations, 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 controversy over the 160-acre limitation ranged with greater intensity. Of the 16,807,000 acres subject to the excess lands provision in all Bureau of Reclamation projects throughout the United States in 1977, fully 4,697,051 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 meeting 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.
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 engineers. The Bureau approached the problem of California's water supply from a broad perspective that took into account the needs of neighboring western states. It studied 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 Southern 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 a project of the 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 courses of Southern California's water supply and diversions to other states. Instead, Edmonston proposed a smaller project to divert water from the Feather River to a multi-purpose dam, reservoir and power facility near Oroville which would control flooding, and transport 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, chose not to construct a water supply project of any size and was poorly organized to undertake a project of the dimensions Edmonston proposed. There were State-constructed delivery systems for Northern California agencies with responsibility for some water 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.

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 Vallecitos River Project Association. Enthusiasm for the project, however, remained concentrated in the agricultural and cultural interests of the San Joaquin Valley. Edmonston had succeeded in enlisted urban allies in the Santa Clara Valley by including the Alameda-Santa Clara-San Benito Aqueduct in his 1931 proposal to supply the rapidly expanding communities of the South Bay. But most water interests in the north were unhappy with plans to expand the "state's" water supply 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.

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 the state's water supply, and by committing themselves to a large alternative source of water from the proposed state project. And, although Southern California knew 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 delivery contracts 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, Jr., 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, as known as the Burns-Porter Act, passed the Legislature in 1969, subject to ratification by the voters at the 1970 General Election. In addition to authorizing $1.75 billion in general obligation bonds to finance construction of specific state water facilities, the act provided for future dams on northern rivers and a drain to remove overdrawn groundwater basins in agricultural areas. The act also provided for an amendment to the state constitution 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, Jr., 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, as known as the Burns-Porter Act, passed the Legislature in 1969, subject to ratification by the voters at the 1970 General Election. In addition to authorizing $1.75 billion in general obligation bonds to finance construction of specific state water facilities, the act provided for future dams on northern rivers and a drain to remove overdrawn groundwater basins in agricultural areas. The act also provided for an amendment to the state constitution 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, Jr., 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, as known as the Burns-Porter Act, passed the Legislature in 1969, subject to ratification by the voters at the 1970 General Election. In addition to authorizing $1.75 billion in general obligation bonds to finance construction of specific state water facilities, the act provided for future dams on northern rivers and a drain to remove overdrawn groundwater basins in agricultural areas.

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 $1.30 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, was required that the state not impair contracts for sale and delivery of water during the lifetime of the bonds. The campaigns for authorization of the bonds in 1969 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 of California opposed the project and many people felt that the 160-acre limitation was desirable in order to preserve small family farms. Organized labor which was as one of the most resolute supporters of support for public works projects of every kind, split on the issue of the bonds. While the teams, 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 farmers. 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 the natural 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 expanded their efforts to pump the water they required.
Service Areas and Facilities

Deliveries

WATER CONTRACTORS
(Construction Acres-Foot)

Feather River
Last Chance Div WD 18,199
Plumas FGWOCD 417
Butte County 356
Thermolite ID 462
North Bay
NapaFGWOCD 6,916
South Bay
AGFC/SGFC (or) 15,179
Alameda Co. WD 6,760
Santa Clara Valley WD 103,087
San Joaquin
Tracy & CC 4
Oakland WD 7,286
Kings County 1,200
Empire WSD 6,626
Tulare Lake WSD 761,202

Deliveries to the water contractors from October 1974 through September 1975.

Energy Generation, Use, and Water Pumped

Southeastern California

MWSC Southern California 679,050
Crestline Lakes & Agricultural WD 708
San Bernardino VNWD 5,885

Total waterr pumped

Reservoir Capacities

Project reservoirs have a total storage capacity of about 30 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: During low-flow conditions, water must be stored in advance to ensure there is enough water available to meet the higher demands of late winter and early spring. The system must then be able to balance supply and demand over the entire reservoir capacity, while also considering other uses such as for navigation, flood control, and power production. Therefore, the reservoir capacities must be carefully managed to ensure adequate water supply for all users.
alternative sources of water such as desalinization, 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 revenue, which project proponents hoped would provide another $500 million by the time these funds were needed for construction. But the Davis-Crummy 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, headlined a 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 El 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 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, united 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 Lake to the Leavitt 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

<table>
<thead>
<tr>
<th>CONTRACTOR Type of Water</th>
<th>1975 Actual Delivery</th>
<th>1975 Contracted Entitlement</th>
<th>Maximum Annual Entitlement</th>
<th>First Year of Maximum Entitlement</th>
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<tbody>
<tr>
<td>Feather River Service Area</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>1. Butte County</td>
<td>Entrainment Water</td>
<td>2100</td>
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<td>2. Lassen County</td>
<td>Entrainment Water</td>
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<td>50</td>
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<td>3. Plumas County Flood Control and Water Conservation District</td>
<td>Entrainment Water</td>
<td>1,000</td>
<td>1,000</td>
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<tr>
<td>4. Tehama County</td>
<td>Entrainment Water</td>
<td>250</td>
<td>250</td>
<td>250</td>
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<tr>
<td>5. Yuba City</td>
<td>Entrainment Water</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>North Bay Service Area</td>
<td></td>
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</tr>
<tr>
<td>6. Napa County Flood Control and Water Conservation District</td>
<td>Regulated Delivery of Local Supply</td>
<td>6,000</td>
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<tr>
<td></td>
<td>Entainment Water</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
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<td></td>
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<td></td>
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<tr>
<td>South Bay Service Area</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Solano County Flood Control and Water Conservation District</td>
<td>Regulated Delivery of Local Supply</td>
<td>50,000</td>
<td>50,000</td>
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<tr>
<td></td>
<td>Entainment Water</td>
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</tr>
<tr>
<td>2. San Luis Obispo County Flood Control and Water Conservation District</td>
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</tr>
<tr>
<td>San Joaquin Valley Service Area</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Central Valley Drainage District</td>
<td>Regulated Delivery of Local Supply</td>
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<td>1,000</td>
<td>1,000</td>
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<tr>
<td></td>
<td>Entainment Water</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Entitlement Water

The configuration of water deliveries shown on the map of the State Water Project is scheduled to change dramatically under the provisions of the Proposition 8. The actual deliveries made to water contractors in 1972 with the amounts by which they were exceeded before the 1972 contract are stipulated in the current contracts; the actual dates when deliveries will reach these maximums may be deferred if water requirements are not met to ensure adequate supplies for the needs of the Delta Pool. The actual dates when deliveries will reach these maximums may be deferred if water requirements are not met to ensure adequate supplies for the needs of the Delta Pool. The actual dates when deliveries will reach these maximums may be deferred if water requirements are not met to ensure adequate supplies for the needs of the Delta Pool.
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 the South, since 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 project facilities run into San Francisco Bay and the estuary.

The San Luis site was included as well in Edmonston’s original plans for the Feather River Project in 1931. 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 1944 and sales continued for several years, supplemented by revenue bonds backed by hydroelectric power sales and by the use of $225 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 108,000 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, 15 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.

<table>
<thead>
<tr>
<th>Hydrologic Basin</th>
<th>Applied Water (acre-feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Coastal</td>
<td>707,000</td>
</tr>
<tr>
<td>Sacramento Basin</td>
<td>6,017,000</td>
</tr>
<tr>
<td>North Lahontan</td>
<td>420,000</td>
</tr>
<tr>
<td>San Francisco Bay</td>
<td>240,000</td>
</tr>
<tr>
<td>Delta-Central Sierra</td>
<td>2,474,000</td>
</tr>
<tr>
<td>San Joaquin Basin</td>
<td>5,655,000</td>
</tr>
<tr>
<td>Tulare Basin</td>
<td>10,984,000</td>
</tr>
<tr>
<td>South Lahontan</td>
<td>307,000</td>
</tr>
<tr>
<td>South Coastal</td>
<td>302,000</td>
</tr>
<tr>
<td>Colorado Desert</td>
<td>3,317,000</td>
</tr>
</tbody>
</table>
service areas. After 1983, when the project's current energy contracts will expire, transportation charges for areas south of the Tehachapi 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 irrigating approximately two million acres of the Central Valley served by 136 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 33 percent of the costs of the Central Valley Project. It has also been estimated that public power sales from the Bureau's generating plants subsidize approximately 68 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 37 percent, while power users pay 72 percent and municipal and industrial users about 10 percent. Ever since the completion of the Central Valley Project, serving residents and industrial customers along the San Joaquin Valley, residents of Coalinga had to bring their produce to the distribution plant shown here to purchase their water for household use. Water deliveries from the project have enhanced the development of sophisticated agriculture only possible in parts of the nation where the summer rains do not fall. The tomatoes shown here are being processed for market.

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 intense agricultural activities which water deliveries have helped to bring about in the San Joaquin Valley at left.

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 projects, 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 Feather River at Dorris. Water from this project would travel through a 25-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 Dorris 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 release water to unappropriated water to be impounded by many new Bureau of Reclamation dams. 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 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 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 of the Central Valley Project's planned facilities are thus somewhat uncertain. The New Melones project, although still proceeding, has met with persistent opposition. Completion of the Auburn Dam has been held up by concern 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 reexamination 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 additional 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 surest way to provide 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 for 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 water management techniques to meet the expanding range of demands that are being placed upon the water supplies now available.
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 economic and social development it has fostered.

The wealth we have invested in the transformation of the natural waterscape has worked to make California the most productive and agriculturally productive state in the nation. In the process, however, we have become a culture which is dependent upon water as a great water-basin prerequisite for the primary production. The weath we have invested in the natural water system by examining the profound changes this system has wrought in the natural water baseline, the development of the modern water system, however, is more than a century, Californians have remade the natural water system by examining the profound changes this system has wrought in the natural water system by examining the profound changes this system has wrought in the natural water system.

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 evaporation 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, water 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 streams and altered the concentration of sediments and nutrients these rivers once carried. As a result, the modern water 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 natural alluvial floodplains in other 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 waterscape, the ocean populated under a gentle Mediterranean climate, extends in the modern water system and the California desert 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 River have been reduced and surface water has been used to recharge the groundwater basin, thus enabling the basin to hold its own against saltwater intrusion.

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 valuable advantage in instances where it is to be used for air conditioning and certain other industrial uses in which water's characteristic 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 pumping of a groundwater basin, however, may lead to subsidence of the land surface and, in some coastal areas, the usefulness of a given groundwater reservoir may be impaired by saltwater intrusion.

Saltwater intrusion can occur wherever the natural seaward hydraulic gradient is reversed, either conditions favoring the landward movement of sea water 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 Mexico Bay, causing the abandonment of wells in San Diego's Old Town pumping field. Seasonal saltwater intrusion was noted as well in the Tulare and San Joaquin River basins in San Joaquin County. And along the San Luis Reservoir 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 30 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 occurs in the Ventura Basin and Los Angeles County, where groundwater levels fell to as much as 100 feet below sea level. Although seawater was evident in the most of the West Basin were still below sea level in 1970, saltwater intrusion had been revealed by the development of a barrier reef created by injecting Colorado River water into a line of 93 wells in Orange County. Pumping from wells has 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 overdrafts in California, subsidence became a noticeable problem by the 1920s. By 1970 estimated 5,200 square miles of the valley had dropped to a maximum of 26 feet in the area south 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 considerable 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 120,000 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. Extensive subsidence became evident in 1933. The rate of subsidence declined, however, during the next few years the valley experienced from 1936 to 1943 and groundwater levels in some parts of the valley rose as much as 36 feet.

After World War II the Santa Clara Valley underwent intensive urban and industrial growth as the area's population increased from 251,000 in 1940 to 500,000 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 was 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 Delta-Mendota Project. These deliveries were used both on the surface and to recharge the depleted aquifers. In 1963, 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 rose in more than a hundred wells now an average of about 60 feet, and land subsidence was consequently brought to a halt.
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 barely 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 persist 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

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Native or Year Introduced</th>
<th>Commercially Fished</th>
<th>Status Active or Year Commercial Fishing Ended</th>
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</thead>
<tbody>
<tr>
<td>American Shad</td>
<td>1871</td>
<td>Sacramento-San Joaquin System</td>
<td>1957 Active</td>
</tr>
<tr>
<td>Asian Clam</td>
<td>1870-75</td>
<td>Sacramento-San Joaquin System</td>
<td>1957 Active</td>
</tr>
<tr>
<td>Bullfrog</td>
<td>Native</td>
<td>Statewide</td>
<td>1957 Active</td>
</tr>
<tr>
<td>Carp</td>
<td>1872</td>
<td>Sacramento-San Joaquin System; Clear Lake; Lake Almanor and other reservoirs</td>
<td>1957 Active</td>
</tr>
<tr>
<td>Crayfish</td>
<td>Native and introduced 1900-25</td>
<td>Sacramento-San Joaquin System</td>
<td>1977 Active</td>
</tr>
<tr>
<td>Lahontan Cutthroat Trout</td>
<td>Native</td>
<td>Lake Tahoe</td>
<td>1957 Active</td>
</tr>
<tr>
<td>Lake Trout</td>
<td>1880</td>
<td>Lake Tahoe</td>
<td>1957 Active</td>
</tr>
<tr>
<td>Mullet</td>
<td>Native</td>
<td>Salton Sea; Colorado River</td>
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<tr>
<td>Pond Тугра</td>
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<td>1962 Can be taken for scientific and educational purposes only.</td>
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<tr>
<td>Roughfish (Gizzard, Blackford, Hardhead)</td>
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<td>Clear Lake; Sacramento-San Joaquin System</td>
<td>1957 Active</td>
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<tr>
<td>Sacramento Perch</td>
<td>Native</td>
<td>Sacramento-San Joaquin System</td>
<td>1957 Active</td>
</tr>
<tr>
<td>Sacramento Pike or Squawfish</td>
<td>Native</td>
<td>Sacramento-San Joaquin System</td>
<td>1957 Active</td>
</tr>
<tr>
<td>Salmon (all species)</td>
<td>Native</td>
<td>Smith; Klamath; Sal; Mod; Russian; Sacramento-San Joaquin System</td>
<td>1992 Can be taken for scientific and educational purposes only.</td>
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<tr>
<td>Steelhead (Rainbow Trout)</td>
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<td>Smith; Klamath; Mod; Russian; Sacramento-San Joaquin System</td>
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<tr>
<td>Striped Bass</td>
<td>1979</td>
<td>Sacramento-San Joaquin System</td>
<td>1935 Can be taken for scientific and educational purposes only.</td>
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<tr>
<td>Sturgeon (White and Green)</td>
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<tr>
<td>White Catfish</td>
<td>1874</td>
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<td>1953 Can be taken for scientific and educational purposes only.</td>
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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 be taken by sport fishermen or under special exceptions such as those granted to certain Indian tribes on the Klamath River.
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 is 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 downstream these diversions become strangled 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 these agencies—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.

<table>
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<tr>
<th>Type of District</th>
<th>Water District Organization</th>
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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.
during a flood in October 1969, Tulare Lake once extended to the point where it could be seen encircling the inner shore of Tulare Lake. The Basin at that time was kept the lake basin dry in most of the Central Valley. The area formerly under water which inundated 139 square miles of the Central Valley, for agriculutre. The courts have decided whether some or all of these new uses 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

**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, "in far from meaning that the patentee 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 riparian rights. 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.

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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 personal domestic purposes upstream riparian owners may take as much water as necessary, even if it has the effect of depriving riparian owners downstream of any share of the supply.

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 bring 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 non-riparian. With most economic resources, the answer is simply to buy the resource from the owner and transport it to the most 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 not effective. The purchaser 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 appropriators, 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 1926 constitutional amendment did have 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 putting 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 both in 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
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. As 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
Marines 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, the river's 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 potable 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 in 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 appropriators, none addressed the problem which confronted water planners in the South Coast in the 1940s of balancing and integrating imported supplies and local supplies. 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 Los Angeles and Others, 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 extractions 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 extractions. 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, private 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 priority of first use in time, first in right. Urban development in the Raymond Basin made unnecessary the resolution of the interplay between 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 followed it 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 "dissension"—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 was 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, a "dissension" that would have bankrupted a lesser litigant.

The cost of these plenary adjudications was proving monumental. The legal and engineering processes which 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
California pumps more water from the ground then 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 Intensive Intense pumping. Although Intense pumping does not necessarily mean that all the hydrologic planning areas within some of the groundwater basins shown here all have a known total storage capacity of potentially extractable groundwater which is known Intense pumping in the South Coastal Plan 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. The basins identified here as undeveloped underlie less than 15 million acre-feet in 1972, as indicated in the chart comparing groundwater pumping in the state’s major hydrologic planning areas. Intense pumping in the South Coastal Plan 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. Undeveloped Basins Developed Basins

Kara Pumpage in 1972

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 actually impart 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 scheme:

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

Groundwater Basin Characteristics

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<th>Basin Name</th>
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Groundwater Basin Characteristics

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<th>Total</th>
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<th>Known Storage Capacity</th>
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<td>200</td>
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<tr>
<td>North Luhitan</td>
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<td>100</td>
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</tr>
<tr>
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Groundwater Basin Characteristics

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<th>Known Storage Capacity</th>
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Groundwater Basin Characteristics

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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 adversarial trial was thereafter resorted to.

Such litigation as a result 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 invisible 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 those agencies in the context of traditional rights. As a result of the Raymond Basin case, all pumping from a groundwater basin were encouraged to fill 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 pumping can obtain prescriptive rights within a groundwater basin as against any public entity. This unanimous decision had the effect of placing the private plumes 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 private pumping 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 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 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 decisions for water increase, the pressure will continue to build to restrain historic imports 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 "watercreep" and contemplated transfers from the abundance of the North Coast to the arid areas of Southern California have seen California's Water and Scenic Rivers Acts enacted 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...
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 increments on the columns indicate 10,000 c.f.s. intervals. A flow of 10,000 c.f.s. is the smallest quantity represented by the 'white' column base. For flows less than 10,000 c.f.s., the columns divide 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 colored bar at the top of the column. If the flow does not exceed a 5 year flood, the top of the column is colored only in the blue class.

<table>
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<tr>
<th>Instantaneous Peak Flow (cubic feet per second)</th>
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<tbody>
<tr>
<td>1,000,000</td>
</tr>
<tr>
<td>500,000</td>
</tr>
<tr>
<td>200,000</td>
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<td>100,000</td>
</tr>
<tr>
<td>50,000</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

Flood Recurrence Frequencies

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

*Note: Yearly maximum capacity to regulate more than one percent of average annual stream flows.*

*Flood Recurrence Frequency figures are derived from the "Peak Type III" distribution prescribed by the U.S. Water Resources Council.*

Where no column appears for a given year, that indicates incomplete annual flow records.
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, which in 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 an important 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 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, 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. Snowmelt floods are characterized by high rates of runoff and usually lower altitudes along the stream channel toward the drainage divide.

When the annual peak flows for the rivers on the peak streamflows platform 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 cubic feet per second, while the corresponding ten-year flood for the Feather River is 225,000 cubic feet per second.
The principal features of the Eel River floodplain receive prominence today to the photograph on this page. The oxbow lakes and curvilinear 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 1980 of the continuation of the Eel's protected status under the law.

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 1965. 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 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
Evidence linking reservoir construction and earthquakes is still lacking, but the threat of agricultural areas and from a 100-year flood for urban development has occurred on land subject to periodic inundation under natural conditions. Extensive road generaL current minimum standards attempt to State law currently requires Ihe areas. Flood control is particularly necessary in urban region and in the Sacramento Basin. These two areas whose failure due to the flow of large volumes of water is compounded by the fact that drought is a natural calamities, and drought recurs capriciously. In California, the severity of a drought tends to be a long-duration 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 sumer 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 sign 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 ground water discharger, runoff is the third form of natural storage to be affected by drought, and the depletion of ground water results in reduced streamflow during rainless periods, but as the duration of the drought extends, the magnitude of water in underground storage decreases. Streamflow is reduced. The eventual destruction of streams during a drought results from the absence of surface runoff and the depletion of ground water.

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 created the most severe drought of this century in California. During the 23 months from November 1975 through November 1977, many locations received little rainfall than would be expected during an average 12 months. The precipitation map for water year 1977 in
Drought Water Years 1976/1977

Percent of Average Precipitation and Snowpack
Oct 1, 1975 - Sep 30, 1976

Percent of Average Precipitation and Snowpack
Oct 1, 1976 - Sep 30, 1977

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

Water Balances
Monthly differences between the natural water 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 33 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 one-third of normal. Statewide precipitation for 1977 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 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 of water for use in Northern California by increasing its water withdrawal from the Colorado River, and approximately 130,000-acre feet of this water was delivered to the San Francisco Bay Area. San Bernardino relinquished 93 percent of its entitlement.

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<td>3565</td>
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</tr>
<tr>
<td>Contra Costa Co. WD</td>
<td>18414</td>
<td>14633</td>
<td>-3781</td>
<td>-21%</td>
</tr>
<tr>
<td>Santa Clara</td>
<td>5769</td>
<td>2901</td>
<td>-2868</td>
<td>-50%</td>
</tr>
<tr>
<td>San Mateo</td>
<td>2302</td>
<td>1492</td>
<td>-810</td>
<td>-35%</td>
</tr>
<tr>
<td>Daly City</td>
<td>1440</td>
<td>1025</td>
<td>-415</td>
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</tr>
<tr>
<td>Hayward</td>
<td>2737</td>
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<td>-981</td>
<td>-36%</td>
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<tr>
<td>Sunnyvale</td>
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<td>2859</td>
<td>-1124</td>
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<tr>
<td>Marin MWD</td>
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<td>1848</td>
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<td>North Marin Co. WD</td>
<td>1160</td>
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<td>142118</td>
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<td>Bakersfield</td>
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<td>6087</td>
<td>-1551</td>
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<tr>
<td>Modesto</td>
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<tr>
<td>Merced</td>
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<td>Sonora-Jamestown</td>
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<td>220</td>
<td>-47</td>
<td>-17%</td>
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<tr>
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<td>-12648</td>
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</tr>
<tr>
<td>Long Beach</td>
<td>10873</td>
<td>8148</td>
<td>-2725</td>
<td>-25%</td>
</tr>
<tr>
<td>San Diego</td>
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<td>23584</td>
<td>-1760</td>
<td>-7%</td>
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<tr>
<td>Anaheim</td>
<td>8479</td>
<td>7530</td>
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<tr>
<td>Riverside</td>
<td>6755</td>
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<td>-12%</td>
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<td>Santa Barbara</td>
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<tr>
<td>Oxnard</td>
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<tr>
<td>Ventura</td>
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<td>924</td>
<td>-117</td>
<td>-11%</td>
</tr>
<tr>
<td>Santa Maria</td>
<td>1295</td>
<td>1068</td>
<td>-227</td>
<td>-18%</td>
</tr>
<tr>
<td>Total Subtotal</td>
<td>157413</td>
<td>137660</td>
<td>-19753</td>
<td>-12%</td>
</tr>
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</table>
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 $400 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 non-irrigated 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 40 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 pumping 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.

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.
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 hydrotlectric 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...
Urban Water Use and Price

The height of the column represents the 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 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.

<table>
<thead>
<tr>
<th>Price</th>
<th>Water Use (in gallons/capita/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 and below</td>
<td>201-300</td>
</tr>
<tr>
<td>301-400</td>
<td>401 and above</td>
</tr>
<tr>
<td>500</td>
<td>600</td>
</tr>
<tr>
<td>700</td>
<td>800</td>
</tr>
<tr>
<td>900</td>
<td>1000</td>
</tr>
</tbody>
</table>

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 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 lower value uses even when the possessors of the right to such use are 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 amendment of water’s 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 some 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 $57 per 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 perverse 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 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 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 water a referee is willing and able to produce and make available for sale in the market at each possible price during a specific time period.

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 to hold or sell a system like the State Water Project, the people are both buyers and sellers and the effect of price and quantity, however, is essentially the same; for, in such a situation, regulation, legal constraints, regional differences in consumer and economic interest groups, and our willingness and ability to pay the costs of development, all act in place of the normal forces of supply and demand to fix a unique point at which Q1 and P1 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 is shown in the two-page map in this chapter of a section of the San Joaquin River 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 uses of water include sanitation, bathing, laundry, dishwashing, and cooking; these uses are primarily a function of the size and

---

**Trends in Urban Water Use**

<table>
<thead>
<tr>
<th>City</th>
<th>1941-50 Average Use (gallons per capita per day)</th>
<th>1951-60 Average Use (gallons per capita per day)</th>
<th>1961-70 Average Use (gallons per capita per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eureka</td>
<td>80</td>
<td>104</td>
<td>131</td>
</tr>
<tr>
<td>Sacramento</td>
<td>249</td>
<td>253</td>
<td>264</td>
</tr>
<tr>
<td>San Francisco</td>
<td>101</td>
<td>115</td>
<td>130</td>
</tr>
<tr>
<td>Fresno</td>
<td>241</td>
<td>333</td>
<td>328</td>
</tr>
<tr>
<td>Santa Barbara</td>
<td>124</td>
<td>153</td>
<td>172</td>
</tr>
<tr>
<td>Los Angeles (city &amp; parks)</td>
<td>125</td>
<td>157</td>
<td>169</td>
</tr>
<tr>
<td>Los Angeles (San Fernando)</td>
<td>201</td>
<td>205</td>
<td>194</td>
</tr>
<tr>
<td>San Bernardino</td>
<td>213</td>
<td>217</td>
<td>208</td>
</tr>
<tr>
<td>San Diego</td>
<td>120</td>
<td>123</td>
<td>142</td>
</tr>
</tbody>
</table>

*Includes only 1949-50

In addition to the differences between cities in average per capita water use, particular outdoor uses for such things as garden irrigation. Cities in the coastal zone experience a greater water demand due to warmer inland locations. Related to this is the size of the yard and the types of plants which are grown. Suburban areas have large lawns, therefore more plants to water. In addition, exotic plants need more water than native species which are often adapted to California's rainless summers. Urbanized areas with smaller lots, higher population densities, and more surface areas will generally have a lower rate of use.

Another important factor is the amount of wealth and the number of members of the community. These differences are reflected in the amount of water used in the home. In addition, it is likely that water use on an average annual basis is increasing, in part by a product of the increased affluence of society as a whole. One study showed that of every ten dollars of income earned, about 1.25 dollars will be spent for water use. An additional 1 dollar will be spent in excess of what would be used if it were about 35 gallons of water. Consequently a family in Los Angeles earning $30,000 annually may theoretically consume some 300,000 gallons of water than more than a family making $10,000.
Crop Patterns and Applied Water

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.

Crop Types and Land Use

<table>
<thead>
<tr>
<th>Crop Types and Land Use</th>
<th>Applied Water (depth)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subtropical Fruits</td>
<td>0.0 - 1.0 feet</td>
</tr>
<tr>
<td>Deciduous Fruits and Nuts</td>
<td>1.1 - 2.0 feet</td>
</tr>
<tr>
<td>Grapes</td>
<td>2.1 - 3.0 feet</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>3.1 - 4.0 feet</td>
</tr>
<tr>
<td>Miscellaneous Truck</td>
<td>4.1 - 5.0 feet</td>
</tr>
<tr>
<td>Cotton</td>
<td>5.1 - 6.0 feet</td>
</tr>
<tr>
<td>Safflower</td>
<td>6.1 - 7.0 feet</td>
</tr>
<tr>
<td>Miscellaneous Field</td>
<td>Not Irrigated</td>
</tr>
<tr>
<td>Rice</td>
<td></td>
</tr>
<tr>
<td>Grain and Hay</td>
<td></td>
</tr>
<tr>
<td>Alfalfa</td>
<td></td>
</tr>
<tr>
<td>Pasture</td>
<td></td>
</tr>
<tr>
<td>Fallow and Idle</td>
<td></td>
</tr>
<tr>
<td>Semiagricultural</td>
<td></td>
</tr>
<tr>
<td>Urban</td>
<td></td>
</tr>
<tr>
<td>Native Vegetation</td>
<td></td>
</tr>
</tbody>
</table>

Key to Transect Alignment

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.
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 such as 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.

**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 or 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 future 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 least costly plants 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. Where 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 overcharge 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 have a significant effect upon the differences in agricultural water prices. For very end 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 use 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 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 agriculture 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 artificially 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 serve the agricultural community, jobs are created, and land values go up. But 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

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<table>
<thead>
<tr>
<th>CROP</th>
<th>IRRIGATED ACREAGE (acres)</th>
<th>Percent</th>
<th>APPLIED WATER (acre-feet)</th>
<th>Percent</th>
<th>TOTAL VALUE TO PRODUCER ($/acre)</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa (hay and grain)</td>
<td>1,341,175</td>
<td>47</td>
<td>6,732,100</td>
<td>54</td>
<td>251,989,000</td>
<td>27</td>
</tr>
<tr>
<td>Cotton (lint and seed)</td>
<td>981,700</td>
<td>34</td>
<td>3,874,700</td>
<td>31</td>
<td>305,937,000</td>
<td>33</td>
</tr>
<tr>
<td>Grapes (all types)</td>
<td>544,805</td>
<td>19</td>
<td>1,903,350</td>
<td>15</td>
<td>368,706,000</td>
<td>40</td>
</tr>
</tbody>
</table>
| 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. The table illustrates, however, the crops which use the greatest acreage and consume the largest volumes of water are not necessarily those which yield the highest value to the producer.
subsidies could, however, be given in other ways so as to afford an even higher multiplier effect.

Even though land owners may achieve 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 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.
from stream sediments. As hydraulic mining developed, associated with the gold mining activities and to provide 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 foods 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, newswrap, fine paper, tissues, milled pulp, roofing felts, and many specialty products. Wood is fed to digesters where water, steam, and chemicals act to separate the individual fibers. The fibers are blown into pots 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 hypochlorite, chlorine dioxide, or peroxyde, 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

<table>
<thead>
<tr>
<th>Industry</th>
<th>Water Intake</th>
<th>Water Discharge</th>
<th>Water Consumption</th>
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<tbody>
<tr>
<td>Transportation Equipment</td>
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<tr>
<td>Food &amp; Kindred Products</td>
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<tr>
<td>Electronic Equipment</td>
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<tr>
<td>Machinery, except Electronic</td>
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<td></td>
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<tr>
<td>Fabricated Metal</td>
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<td></td>
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<tr>
<td>Stone, Clay, &amp; Glass Products</td>
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<tr>
<td>Chemicals &amp; Allied Products</td>
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<tr>
<td>Primary Metal</td>
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<tr>
<td>Petroleum &amp; Coal</td>
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<tr>
<td>Rubber &amp; Misc. Plastic Products</td>
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<tr>
<td>Instruments &amp; Related Products</td>
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<tr>
<td>Lumber &amp; Wood Products</td>
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<tr>
<td>Paper &amp; Allied Products</td>
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<td>Textile Mill Products</td>
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<tr>
<td>Miscellaneous Manufacturing</td>
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</tr>
<tr>
<td>Leather &amp; Leather Products</td>
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</tbody>
</table>

**Value Added / Water Consumed**

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

**Water for Electrical Power Plant Cooling**

The table compares the kinds and quantities of cooling water used by electric plants for electrical power generation in 1977. Coastal power plants use sea water only once before discharging it back into the ocean. Related water pollution concerns include reductions of more limited water supplies, affecting the amount used 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 refineries, 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 dissolving or milling of clays, the leaching of molten products such as caustic soda, and the emergency dewatering of reactions out of control, such as might occur in the manufacture of trinitrotoluene (TNT). There 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 decoked 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 water user 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 space with the astonishingly rapid expansion of electrical services in America. The first electrical generating plant in California was built in 1884; San Francisco and New York installed their own systems only three years later. By 1889, when the San Francisco Electric 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 Reidsville 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 Fulborn 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 32 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 ground water 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

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. The fraction of the total capacity of the powerhouse is known as the load factor. The lighter color 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.
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 100-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 hydroelectric power plants like the one shown below.

In hydroelectric power 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 23,735 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 Ceres 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 on 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 of 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 normal 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 handle 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 large 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 favorable 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 43-45 feet the Sacramento and Stockton ship channels. The completion of these improvements would permit larger-tonnage carriers and deeper-draft 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
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.

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 the early 1960s, 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-Dolwig 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 35 water projects that include recreational programs as part of their operations.
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 multi-purpose 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 30 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 in-stream 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 interests 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.

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.

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Public Water Recreation Facilities

Operated land includes both landed property and public domain. The extent of water recreation facilities was indicated by: (1) the extent to which public water areas are open to the public and (2) the extent of public access and facilities available for recreation. 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.
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 enhancement 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, biological, 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 granite watersheds of the Sierras, 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 decays. 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.

**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 solids 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 expressed. A concentration of 12 parts per million of dissolved oxygen, for example, is considered quite high, while a concentration of four parts per million is low. Boreo, 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 (i.e., not chemically bound with other elements) is available for respirations 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 deadly 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 the sediments have accumulated in the reservoirs behind the dams. On the Trinity River below Clair Engle Reservoir, however, controlled releases of water have reduced the natural flow of the river that the mainstem 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. Deposted 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. Turbidity 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.

Northern California are in fact non-point source pollutants which release 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 precipitating plants and some rock 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 dilution 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 1979 an estimated 22 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. Heavy metals, pesticides concentrate in plant and animal tissues and many of these compounds are considered to be carcinogenic to humans. Although regulations have been established, relatively little has been done to control these pesticides. Historically, 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 water is also desirable for certain agricultural products such as rice because the algal blooms from 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 soils and organic matter. Some nitrates are generally believed to be found in rainwater. When used by plants, nitrogen usually returns to the soil upon the death of the plants, where some of it is lost by volatilization or leaching. Nitrates in 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 and 7 to 14 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 by probes and water samples are taken 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 process works most effectively within certain pH ranges. Water acidity is also an important factor in aquatic life cycles. 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 converted to nitrate and nitrite at pH levels 8.0 and extremely toxic to fish at pH 6.5 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 in water at different temperatures. Anadromous fish migrate in response to temperature changes and the eggs require water that is around 50 degrees Fahrenheit. Temperature also influences human uses of water. Industrial uses for processing and cooling require water of a certain temperature and temperature also affects the effectiveness of water and sewage treatment processes. Coliform bacteria for example, tend to die more quickly in water with a higher temperature. Water users are also concerned about certain temperatures as aseptic meningitis, infectious hepatitis, and polio.

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 systematic irrigation in the Central Valley Project, the Columbia and Trinity rivers and at Lake Tahoe suggest the breadth of this diversity. The demands placed on the Trinity and San Joaquin rivers for industrial, recreational, and urban development greatly exceeded their capacities. The waters of the Columbia, Trinity, and Klamath rivers in California flow into the Pacific Ocean. The Columbia and Trinity basins have the greatest amount of stream flow and are the most productive areas of salmon production. The Columbia and Trinity rivers are the central part of all water planning in the United States. 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 Columbia and Trinity rivers by diverting water from three new regional treatment plants which would replace the eight plants already located on the Columbia discharge. High flows of polluted, warm and saline effluents were piped to Orange County for discharge into the ocean.

Completing 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 foot 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 dried up and willows and other vegetation began to encroach upon the stream bed, thereby further slowing the river's flow and complicating downstream 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, instream silt control devices 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 nutrients. Runoff from Lake Tahoe is piped out of the basin and construction practices have been controlled for the last 13 years. The rate of new development along the shoreline, however, and the effects of airborne pollutants have resulted in sediment and the growth of algae near the shore and especially in the areas around the mouths of tributary streams. The 20-year plan for Lake Tahoe was 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.

What appears 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.
Surface Water Quality Water Year 1975

Three maps compare the concentration of three principal constituents of water quality in four major systems during the water year 1975. Dissolved Oxygen (DO) and Nitrites (NO₂) are represented in micrograms per liter (μg/L) and Total Dissolved Solids (TDS) in terms of the electrical conductivity of the water measured in microsiemens (μS). Generally, lower levels of TDS and NO₂ indicate deterioration of water quality, while higher levels of DO are beneficial to most uses of water.

Minimum and maximum observed concentrations of these constituents are shown at various locations. Stations have been assigned for a more detailed presentation of data, for time series, and to compare levels 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 unacceptable for various uses.

**Minimum/Maximum Concentrations (Water Year)**

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**Water Quality**

- **Domestic water supply**
- **Industries**
- **Irrigation**
- **Public supply**

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**San Joaquin River System**

- **Klamath River System**
- **Lake McClure**
- **Sacramento River**

A colorless square represents no data.

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**Surface Water Quality**

- **San Joaquin River System**
- **Sacramento River**
- **Lake McClure**
- **Klamath River System**

A colorless square represents no data.
Although early water quality control programs emphasized the installation of sophisticated central sewage treatment systems, increasingly to the construction of such expensive facilities is growing in remote areas like Bolinas Lagoon, where simpler alternative technologies may be more appropriate. The (Conflict) central sewage treatment systems, although early water quality standards, 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 affecting 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 1902 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, 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 ground-water 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 appellate 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 applications. 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 water quality 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.

Then safe, pleasant of water treatment is to remove suspended material and kill possibly pathogenic organisms. The water is filtered either through sand
Sewage Treatment Facilities
Capacities, Treatment Standards & Volumes, 1975

Disposal of Liquid Effluents
Numbers refer to outfall code on Facilities List.
1. Ocean outfall
2. Surface waters
3. Ocean outfall
4. Ground water recharge
5. Ground water recharge
6. Recycling and reuse
7. Other
8. Other

Facilities List
Numbers at left of columns refer to map and increase from north to south.

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Volume Scale
Gallons per day

Treatment Plant Capacities
Seawage plant total capacity and service areas (above) are based on water use at the time of planning.

Treatment Standards
Secondary treatment standards
Non-treatment standards
Primary treatment standards

Facility Abbreviations
MUS Municipal Utility District
PUDP Public Utility District
SD Sanitation District
STP Sewage Treatment Plant
WPFC Water Pollution Control Facility
WQFC Water Quality Control Facility
WRF Water Reclamation Facility
WTRF Wastewater Treatment Facility
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, oil, 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 aeration 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 claims 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.

Treatment against development of this resource stems from the lack of a clear concept of who will utilize reclaimed water, restrictions based on the so-called "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, non-point 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 non-structural 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 air 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.
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 such great demands for water. These needs have been 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 vs. 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
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, Flood
- Surface Irrigation, Border
- Surface Irrigation, Basin
- Sprinkler Irrigation, Solid Set
- Hand Move, or Mechanical Move
- Drip Irrigation
- Sub Irrigation

Hydrologic Basin Planning Area

Klamath River
North Coastal
San Francisco Bay
Central Coast
Santa Clara River
Los Angeles River
Sacramento River
Sacramento-San Joaquin Delta
San Joaquin River
Kings Kern Rivers-Tulare Lake
North High-Desert Lahontan
South High-Desert Lahontan
West Low-Desert Colorado River
East Low-Desert Colorado River
Santa Ana River
San Diego River

Crops
- Alfalfa
- Hay
- Oranges
- Cotton
- Alfalfa-Sorghum
- Corn
- Other Field Crops
- Other Tree Crops
- Total All Year Crops
- Grapes
The grain fields in the photograph at top are an example of dry farming in the Montezuma Hills. In the lower photograph, itself would be drowned if flooded. Efficient method of irrigation in terms of water use, this type also required to deal with specialized problems of ground slope, and the quality, texture, and depth of the earth dikes, is the most prevalent method and has developed efficiently, as in areas where the soil is sandy, the conditions in which flood or furrow irrigation cannot be applied. Furrow irrigation is used for row crops, such as frost control, leaching, or where crops are being grown worse each year, is posed by the problem of Significance to consumers of these commodities 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 cauliflower. 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, the growing 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 production, which is also growing worse each year, is posed by the deterioration of soil quality resulting from soil salinity. The continued application of fertilizers and irrigation water, which usually contains some mineral salts, results in a build-up 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 removal of the salts can be leached out and carried away and the water table lowered. Irrigated croplands that slope usually drain adequately, but small valleys, especially those 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 such 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 the 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, one million tons of new salts will be added to the valley floor yearly, mostly on irrigated lands. Approximately 1.1 million acres, or nearly 3 percent of the irrigated lands 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 from a point west of Bakersfield to a final point of discharge in the tidally discharging 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.

GROUNDDWATER MANAGEMENT

The future productivity of the San Joaquin Valley is threatened by the problem of overdraft of its groundwater supply, supply for Southern California and the protection of water quality in the Colorado seem to have been met, numerous questions remain to be answered. 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 exhausted all 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 provides more than 65 percent of the nation's fruit and vegetables. The state's leading producing counties are the San Joaquin Valley, Imperial Valley, and Santa Clara County, which produces the major portion of the nation's table grapes. California is one of only a handful of states which produce the major portion of the nation's table grapes. California also produces a major share of the nation's lettuce, broccoli, garlic, artichokes, thumbsprouts, potatoes, plums, lemons, almonds, walnuts, olives, avocados, apricots, figs, dates, and cauliflower.

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 uplanded 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.

Irrigation methods are varied in terms of the quantities of water consumed and means of application. The most efficient method is kneeboard check irrigation, which is used 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 uplanded 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.

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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 underlying sources. The success of these negotiations has been due in part to the development of nonjudicial means for bringing effective groundwater management to other areas of California. Groundwater adjudication may be of limited utility. Particularly with regard to the badly overdraft 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 pumps 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. Or, 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 use.

A report by the Governor's Commission to Review California Water Rights Law in 1978 recommended that emphasis be placed upon development of nonjudicial 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 60 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; 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 of 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 rice, agricultural lands, producing crops worth over $500 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 to the natural conditions are exacerbated 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.

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 leasing 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 San Francisco Bay and resist the ebb and flow of the ocean tides. The water of issues surrounding the Delta involve questions of efficiency, monetary gains...
Water quality in San Francisco Bay and the Delta is the product of a complex and 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 cycles of water exports. Differences between the limits of salinity intrusion during the dry years of 1921 and 1931, and between the wet years of 1941 and 1969 reflect the impact 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, waste-water 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, 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. 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 terminus, 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 for its future water needs has been opposed with the contention that the Columbia would provide only 2.7 million acre-feet of water to meet designated needs up to the end of the century. The diverse interests competing for water and the dependence of this proposal upon extensive state and federal financial participation, however, suggest that it is impossible for state planners now in the future to implement this plan or something equally 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 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 policy of water conservation and development projects in the Pacific Southwest Water Plan which would have substantially reoriented the water supplies of California, Arizona, Nevada, Utah, and New Mexico. Within California the plan, among other things, called for diverting 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. Dune, 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 $4.2 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 River through eastern Oregon at a cost then estimated at $5.2 billion.

Other water planners meanwhile turned their eyes toward the Columbia River. In 1964, Frank Z. Pinky, a private consulting engineer retained from the Army Corps of Engineers and the Department of Water Resources, proposed pumping 33 million acre-feet of water from the Columbia River and diverting 4,900 feet over the mountains to Goose and Shasta lakes, whence it would flow south to Lake Mead. Pinky 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 engineer firm in 1963 proposed a novel method for achieving interbasins transfers within California through a pipeline under the ocean which the Bureau of Reclamation estimated would cost $20 billion. The so-called NESCOP 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 water basins with a total area nine times the size of California, would cost an estimated $200 billion and require over 50 years to construct.

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 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 1960's. 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

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**PIPE DREAMS**

**Western Water Project (Pirkey Plan)**

**North American Water and Power Alliance (NAWAPA)**

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**Snake-Colorado Project**
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 urgency 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 sur­

Since 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 1979, 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 environment.

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 subsidy amounts to more than $1,100 per acre-foot. This federal policy no doubt had merit during the first half of this century as a means of speeding 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 long-time 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 transfers 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.
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.

**Interregional Transfers, 1972**

This graphic illustrates the quantity of water, in acre-feet, that was imported and exported by each hydrologic basin during 1972. Groundwater pumping alleviates deficits in some basins.

*Exported water does not originate in a basin.*
The photographs on this page provide several examples of the importance of technology in the creation of the modern water system. The invention of the clamshell dredge on the left overhauled reclamation methods and made possible the construction of hundreds of miles of dikes to protect Delta agriculture. Because bottom and conventional wheeled vehicles soon bogged down in the porous, peaty soils 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 impinged on the track-laying vehicles developed for use in the Delta for safe and efficient excavation and reclamation on the right, the houses were built on the periphery of the reclamation area because the land would not support construction. The small, wheeled vehicles soon bogged 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 purposes 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 proved at best a fragmented, 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 value 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 riparian 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 leases it grants in ways designed to protect in-stream uses. It is unsettled, however, whether public or private entities can acquire appropriate 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, is remains to be seen at the time of this writing.

NEW TECHNOLOGY

The course of water development in California has been largely 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 landscape 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 10 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 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.

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.

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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 31,000 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.
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 going 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 un receptive 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 rapidly into the fiscal drought year of 1978, the year of the Jarvis-Cann 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 seem very large in the context of a $20 billion state budget. Furthermore, by the time the Jarvis-Cann 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 (Marilyn 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, the advisory group that was responsible for the design, not 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 interfere with our 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 wrong," 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 have 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 21/2 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) a round magazine and book publishing forever—that once the "piece" is done, then editing, design, illustration, paste-up, and corrections take no time. Ha.

I'd like to focus on that 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 Marilyn Shelton..."
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 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 Kahler, chair 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 track 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 a key around the state before 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 Kahler: "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 new awareness and 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


San Francisco Bay Conservation and Development Commission. San Francisco Bay Plan. San Francisco, CA. San Francisco Bay Conservation and Development Commission, 1960. 260 pages. The San Francisco Bay Plan was adopted by the San Francisco Bay Conservation and Development Commission in 1960. The Plan is designed to preserve and enhance the quality of the San Francisco Bay and its environs. It includes a comprehensive program of actions to be taken by the various agencies and jurisdictions responsible for the area.


HYDROLOGIC BALANCE
Adapted from Department of Water Resources
flow diagram Hydrologic Balance for California.
November 1977.

CALIFORNIA IN CONTEXT
Data provided by Department of Water Resources.

SACRAMENTO FLOOD CONTROL SYSTEM
California Department of Water Resources.
Gallegos, T. J. An assessment of the feasibility of
embankment flood control at the Sacramento River.

historic water development
California Department of Public Works. Division of
Water Resources. Divisions Under the Jurisdiction of California.
Sacramento, CA: State Printing Office, 1971. (Now identified as
Bulletin 74-11).

natural moisture demand
California Department of Water Resources.

for the development of maps and other
natural resources, and hydrologic investigations, was
adapted from material developed by Greg Scharenberg,
Chief of Water Resources for Division of Planning.

Historic Water Development.
California Department of Public Works.
Division of Water Resources. Divisions Under
the Jurisdiction of California.
Sacramento, CA: State Printing Office, 1971. (Now identified as
Bulletin 74-11).

GROWING SEASON ETIQUETTE
California Department of Water Resources.
Bulletin, No. 130-3: Vegetative Water Use in Cali
ifornia. Sacramento, CA: State Printing Office,
1974.

Additional information provided by B. D. Marks of the
Imperial Valley Conservation Research Center, Bealeton, California, in

COLORADO RIVER BASIN 1976
U. S. Department of the Interior, Bureau of
Reclamation. Colorado River Study Water Use and

Additional information provided by the Colorado River
Board of California, Los Angeles.

Area Power Administration.

California Department of Water Resources. 20.
Field Deck: California Water Project. Sacramento,

Pineapple. 1974, Los Angeles Department of Water

Metropolitan Water District of Southern California. Metropolitan Water
District of Southern California. Metropolitan Water
District of Southern California. 1976. Sacramento, CA:

Additional data provided by the Los Angeles Department of
Water and Power.

Los Angeles Department of Water and Power.

Metropolitan Water District of Southern California.
May Monograph Agreements 1977.

Los Angeles, CA: Metropolitan Water District of Southern California.


Los Angeles Department of Water and Power.

Los Angeles, CA: East Bay Municipal Utility District.


SOUTHERN CALIFORNIA URBAN DELIVERY SYSTEM WATER SUPPLY DATA.

Additional data provided by the Los Angeles Department of
Water and Power.

Los Angeles Department of Water and Power.

Los Angeles, CA: East Bay Municipal Utility District.

1976.

SACRAMENTO FLOOD CONTROL SYSTEM.
California Department of Water Resources.
Gallegos, T. J. An assessment of the feasibility of
embankment flood control at the Sacramento River.

additional information provided by B. D. Marks of the
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Los Angeles Department of Water and Power.

Los Angeles, CA: Metropolitan Water District of Southern California.

May Monograph Agreements 1977.

Los Angeles, CA: Metropolitan Water District of Southern California.


Los Angeles Department of Water and Power.

Los Angeles, CA: East Bay Municipal Utility District.


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additional information provided by B. D. Marks of the
Imperial Valley Conservation Research Center, Bealeton, California, in

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Area Power Administration.
Index

We assumed in constructing this volume that many people do not finish reading it to the end but instead turn directly to the subject that interests them most. The contents have consequently been organized to ease a perceptive 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 irrevocable 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 multifaceted topics, as well as to locate specific references to individuals and institutions mentioned in the text.