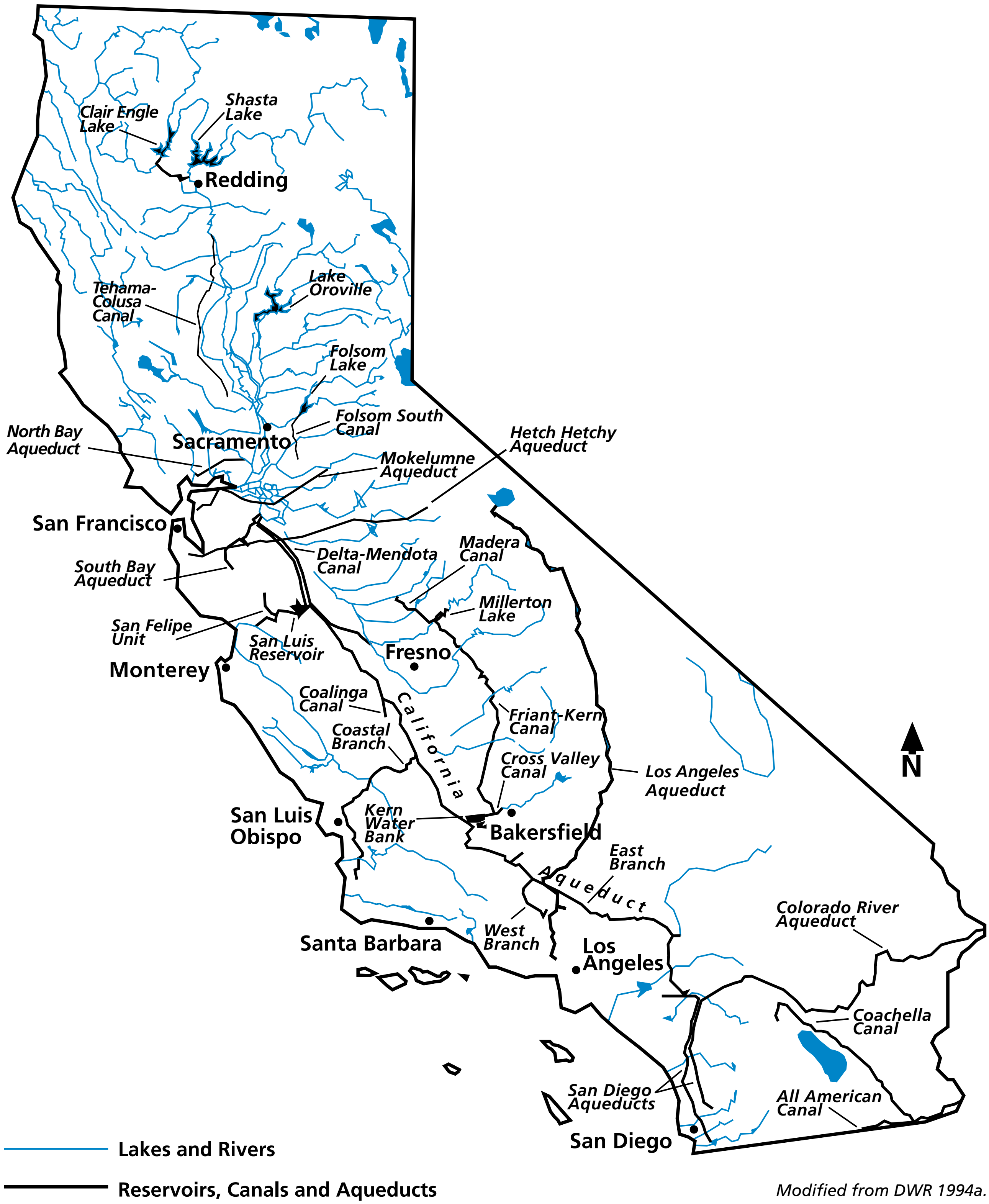
**Figure 1**
**Major State and Federal Water Projects**




*Modified from DWR 1994a.*

# I. California Water 2020

What could California's water situation look like in the year 2020 — twenty-five years from now? The answer is, almost anything: from chaos and conflict to order and cooperation. We present here a positive vision of California's water future. Our crystal ball is, of course, no clearer than anyone else's. Our intention is not to *predict* the future, but to lay out a desirable *possibility* — a vision of California in which true water planning occurs with widespread democratic participation, leading to rational water management, a healthy environment, and cooperation among all affected parties. The vision of 2020 presented here offers a goal to shoot for — an attractive future where water is used efficiently, allocated flexibly, and maintained sustainably for present and coming generations and the environment. The point of generating such a vision is to move away from traditional scenarios of a gloomy, conflict-ridden, resource-short future, toward positive outcomes in which sustainable and equitable water use, as we define it in this report, can be met. Without developing such a vision and exploring its possibilities, California will remain stuck in the quagmire that exists today.

A crucial part of this vision is that it be sustainable. Over the past 12 months, through discussions with a wide range of people concerned with water, we have developed a set of sustainability criteria that are integral to the vision for 2020. These criteria relate to the geophysical characteristics of our water, the environmental dimensions of the resource, and the social institutions set up to ensure reliable supplies.

Defining a vision is important not only for setting goals, but also for thinking about how to attain these goals. A vision makes explicit the underlying values of water and opens the dialogue on the ultimate ends of policy and planning. We explore here how California's various water-using sectors fit coherently together, rather than focusing on just isolated aspects of water.

What will drive the changes we envision? Many economic, political, and cultural forces are at work in society changing our lifestyles, technologies, and institutions. These forces will continue. To reach this positive vision, we do not assume here any significant new supply infrastructures will be built, nor do we assume that drastic advances in technology are necessary. For example, some technological optimists believe that very inexpensive desalination technology may become widely available, obviating any need to think about water efficiency or agricultural policy or industrial structure. We think it best, however, not to assume that this will be the case. Similarly, the changes necessary for achieving sustainable water use in California do not require "heroic" or extraordinary actions on the part of any individual or sector. Instead, these changes are likely to come about by incremental technological innovations, changes in governmental and industrial policies, an evolution in personal values, and changes in culture — all of which are already common characteristics of California society.

***Can a sustainable water future be achieved? Yes, given appropriate attention and will, California's water policies can be substantially modified over the next quarter century.***

Can a sustainable water future be achieved? Yes, given appropriate attention and will, California's water policies can be substantially modified over the next quarter century, just as they have over the past twenty-five years. *Will* a sustainable future be achieved? That is a question that only the public and their elected officials can answer. The dialogue on how to do so must begin now.

This report explores how the state might begin to plan for a sustainable water future, presents our vision of what that future might look like, and discusses how such a vision might be achieved. This section — California Water 2020 — describes what California's water situation could be like in 2020 if efforts to solve California's water conflicts and to plan for a sustainable water future are successful. We then discuss in Section II the need for a new water-planning paradigm and in Section III the sustainability criteria upon which our vision is based. Section IV provides an overview of past and present state water plans and water-use trends in California. Section V presents our assumptions and analysis that supports the 2020 vision. Section VI examines the tools — financial, educational, regulatory, and technological — that can lead toward a sustainable water future. Specific conclusions and recommendations are made in Section VII.

**Figure 2**
## Hydrologic Regions in California


*Source: DWR 1994a.*

# The 2020 Vision

It is now the year 2020. Twenty-five years ago, in the final decade of the twentieth century, the management and protection of California's freshwater resources reached a turning point. The water policies of the first part of the century, which permitted California to become a leading international agricultural and economic force, were beginning to fail, and appeared grossly inadequate to the task of meeting the challenges of the 21st century. Yet official institutions and policymakers seemed unable to look past their traditional tools and practices to try to understand the nature of the new challenges and to develop ways of meeting them.

Two seemingly irreconcilable problems exemplified the paralysis that gripped California water management: the competition between urban and agricultural water interests, and the inability of the state to develop and implement acceptable standards of protection for critical environmental resources such as groundwater aquifers, endangered and threatened species, and critical aquatic ecosystems. To further complicate the problem, the federal and state budget crises of the 1980s and 1990s, and public concern over environmental impacts, effectively eliminated the possibility that major new physical facilities would be built — the traditional response to past water problems. Yet efforts to explore alternatives were not encouraged. As a result, California water policy was so hobbled and confused that it offered no reasonable guidance for complications such as rapid population growth, intersectoral and regional competition for water, large-scale climatic changes, and important, but uncertain technological and institutional changes, all of which we now know to be standard characteristics of our day-to-day life.

Now, the crisis is over and sound water policies are in place for the 21st century. In large part, this change came about because of the natural progression of technological innovation and lifestyles and a continuing willingness on the part of individuals to accept this progression where it improved their quality of life. There is consensus on how to use limited freshwater supplies, which has minimized conflicts and litigation over new proposed policy. A planning process that resolves these conflicts by setting new goals and priorities for water-resource management has been developed, and California officially plans for a sustainable water future.

What does the California water situation look like in 2020 and how did we get here? California's total population has swelled to just under 49 million people — the most populous state in the United States and substantially larger than the entire population of Canada. Only 27 countries worldwide have larger populations, and very few have larger economies. Of this population, more than 47 million live in cities — an extremely high urban population. Three-quarters of the state's people live in just two major urban conglomerations: the greater Los Angeles-San Diego coastal zone and the San Jose-San Francisco-Sacramento metropolitan corridor. Development in this latter region has almost split the Central Valley in two, with a band of urban sprawl stretching east from the Bay Area into the foothills of the Sierra Nevada.

Total water supply remains about the same as it was in the late 20th century. Surface runoff still averages about 70 million acre-feet each year, augmented by flows from the Colorado and Klamath rivers. Annual net groundwater use is balanced by recharge and ranges from 7 to 12 million acre-feet, depending on climatic conditions and availability of other supplies. Perhaps the greatest change in supply from the 1990s is an increase in the annual variability due to the onset of global climatic changes. California water supply has always been highly variable: annual surface runoff in the 20th century varied from a low of 15 million acre-feet to over 130 million acre-feet. By the end of the century, however, periods of extreme years began to occur more frequently. The last 25 years of the 20th century produced new record dry periods for one year, two years, three years, and six years, as well as the wettest years in recorded history. Thus, while average runoff remains about the same, years of both droughts and floods have become more common, complicating the operation of the state and federal water projects. At the same time, by 2020 snowfall and snowpack in the Sierra Nevada have decreased, and peak spring runoff occurs earlier and faster, as warmer average temperatures cause an increase in rainfall and a decrease in snowfall. Hydrologists have begun to accept that these changes, evident in other parts of the world as well, are the result of global changes in the hydrologic cycle related to the greenhouse effect. So far, water managers have been able to modify existing structures and methods of operation to adapt to the changes. Skiers are trying to cope; white-water rafters are delighted.

## A. AGRICULTURAL TRANSFORMATION

As the world's population continued its enormous growth during the first two decades of the 21st century, the importance of California's food exports has increased the significance of maintaining the state's agricultural production at high levels. Yet substantial changes in the structure of the agricultural sector have occurred since 1990. California farmers have always been innovative and flexible, and continuing innovations in the California agricultural sector have produced changes by 2020 of a magnitude comparable with those in the preceding 25-year period: 1970 to 1995. In the early 1990s, water-intensive crops, such as irrigated pasture, alfalfa, cotton, and rice, were being grown on 40 percent of California's irrigated cropland, consumed 54 percent of all agricultural water, yet produced only 17 percent of the state's agricultural revenue. By the turn of the millennium, the growing competition for water from the urban and environmental sector made these practices increasingly unpopular and difficult to sustain. At the same time, however, the realization of the importance of maintaining a vibrant agricultural community in the state helped stimulate the movement toward water reform that permitted the subsequent innovations and restructuring.

By 2020, the agricultural community has begun a significant shift away from growing water-intensive, low-value crops, replacing them with lower water-using crops grown with highly efficient irrigation technology. This shift, driven in part by changes in federal and state water and crop subsidy programs, has caused California to boost its global lead in the production and export of fruits and vegetables, particularly almonds, grapes, walnuts, olives, apricots, pears, and artichokes. From 1990 to 2020, the area of irrigated pasture, alfalfa, rice, and cotton dropped from 40 percent to 26 percent of total state irrigated acreage, with most of that land re-planted in other crops that can be grown on the same land. Overall irrigation efficiency has also risen slightly from 1990 levels. Despite continued urbanization and some land fallowing, the total land under irrigation today is only 4 percent less than it was in 1990.

The net result of these changes is a decline in the amount of water consumed by agriculture in the state from 21.2 million acre-feet in 1990 to 18.7 million acre-feet in 2020 — a reduction of 12 percent. At the same time, overall farm income has risen 12 percent (in constant terms) from 1990 levels. The agricultural population of the state, after declining significantly for the last few decades of the 20th century, has leveled off as a fraction of total state population, as many farms switched away from growing water-intensive low-value crops toward more labor-intensive but highly water-efficient high-value crops. Table 1 summarizes many of these changes.

Land permanently removed from irrigation includes marginal lands in the Central Valley, particularly those susceptible to severe water-quality problems along the west side of the San Joaquin Valley and in the southern regions. On farmland that remains in production, methods that encourage co-existence of wildlife and farming are increasingly prevalent, with the result that pressure has been reduced on many indigenous species. These environmentally-friendly farming methods gained in popularity after federal and state endangered species legislation was revamped in the late 1990s to replace emphasis on individual species with protection of habitat and ecosystems.

In one of the most significant changes in agricultural water policy, all groundwater use and quality is monitored and managed by local groundwater management groups with the guidance of statewide standards. As a result, long-term overpumping of groundwater stocks — one of the clearest measures of the unsustainable water policies of the 20th century — has ended. This serious problem in the mid- to late-20th century led to the permanent loss of over 20 million acre-feet of storage capacity in Central Valley aquifers. As late as 1995, more than one million acre-feet of groundwater were being overdrafted in more than 30 separate groundwater basins. Official state projections in the mid-1990s suggested that total groundwater overdraft of a million acre-feet would continue to 2020 and beyond in the majority of California's 10 hydrologic regions. In three of these regions, groundwater overdraft would have been more than 20 percent of total groundwater use.

**Table 1**
**California Agriculture: 2020 Vision**

| California Totals | 1990 DWR[a] | 2020 DWR[a] | 2020 Vision[b] | Net Change 1990 to Vision | Percent Change 1990 to Vision |
|---|---|---|---|---|---|
| Irrigated Acreage (thousand acres) | 9,570 | 9,302 | 9,145 | -425 | -4.4 |
| Consumed Water (million acre-feet) | 21.3 | 20.1 | 18.7 | -2.6 | -12.2 |
| Applied Water (million acre-feet) | 30.6 | 29.1 | 27.3 | -3.3 | -10.8 |
| Groundwater Overdraft (million acre-feet) | 1.3 | 1.01 | 0 | -1.3 | -100 |
| Farm Income (billion 1988 dollars) | 12.2 | 12.8 | 13.7 | 1.5 | 12.3 |

*[a] All DWR numbers are derived from DWR 1994a, except the groundwater overdraft figures, which come from both 1994a and 1993.*

*[b] Details of the 2020 Vision can be found in Section 5B.*

*DWR: Department of Water Resources.*

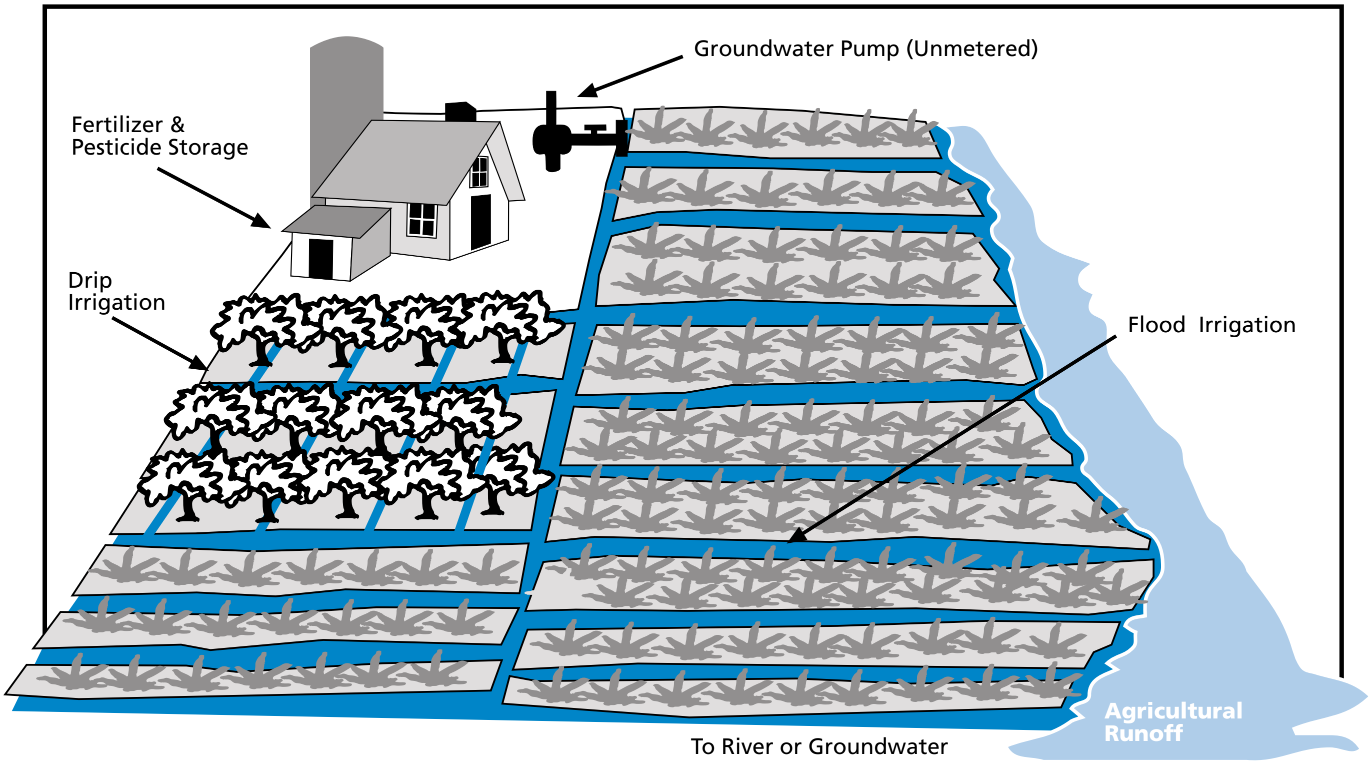
These projections were the result of traditional assumptions about the continued cropping of several low-value, water-intensive crops. Instead, policies implemented in 2002 now permit water marketing and transfers, and changes in state and federal pricing policies for both water and crops after 2000 led to voluntary reductions in the planting of irrigated pasture and alfalfa in these regions. Often farmers replanted that land with other, more water-efficient crops, which simultaneously eliminated the need to overdraft while generating higher farm revenues.

Under the new state and local groundwater management system, groundwater overdraft still occurs in drought years in regions capable of being recharged later, but all groundwater overdraft in aquifers vulnerable to land subsidence, salinity intrusion, or contamination from agricultural chemicals has now been eliminated. Agricultural drainage is strictly controlled to protect ground water in vulnerable regions of the state.

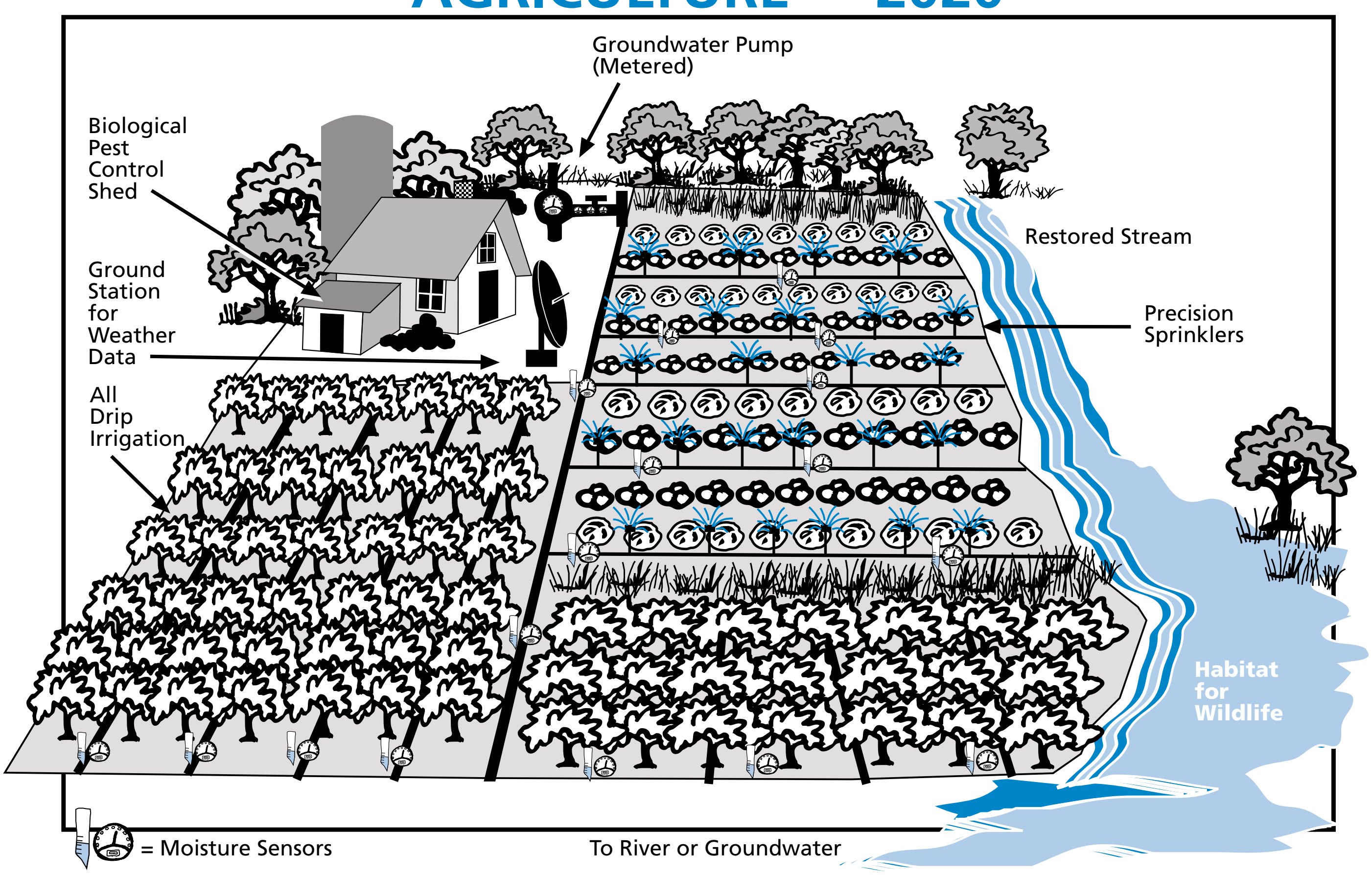
The new water pricing policies also guarantee that surface irrigation water will be available for certain classes of high-quality farmland. Tracts of farmland considered to have high productive values or that support special flora and fauna habitats receive legal protection from urbanization. Legal mechanisms have also been developed and implemented to ensure the availability of adequate water for that land.

Innovations in integrated pest management methods spurred by a rethinking of fertilizers and pesticide use in the 1980s and 1990s, continue to lead to decreased application of chemicals. As a result, the state has witnessed a substantial improvement in water quality throughout the agricultural regions. Human health and the reproductive success of waterfowl show noticeable improvements by 2020, with some of the greatest improvements found in the rural communities of the Central Valley. For the first time in 40 years, the number of California plants and animals on the endangered and threatened species list has begun to decline.

# AGRICULTURE - 1990




# AGRICULTURE - 2020



## The Farm of 2020

Jane Montrose, her brother Tim, and their families own a 700-acre farm in the San Joaquin Valley north of Fresno. They grow Chardonnay grapes, almonds, gene-altered tomatoes, and peaches, with techniques and practices unknown to their parents who grew alfalfa, corn, and traditional canning tomatoes on the same land 25 years earlier. By 2000, the family began to notice that the petroleum-based chemical arsenal on which they depended to control insect and weed pests was losing its potency. At the same time, concern about the reliability of irrigation water led them to begin to plan for the transition away from standard irrigation methods. Since then, the siblings have accumulated a sophisticated understanding of the role of a set of new natural and technological tools, including cover crops, natural composts and mulches, new forms of disease-resistant varieties of crops, beneficial insects and birds, and sophisticated technology for managing water.

Gone are the bare furrows and sterile border strips around their fields that were the requirement of a twentieth-century farmer. In their place are rows of native grasses between the vines and trees, with 15-foot wide hedgerows around every 100-acre field. The perennial grass cover crops suppress many noxious weeds formerly eliminated with herbicides, while simultaneously reducing topsoil loss and erosion on banks and slopes. The hedgerow corridors also provide habitat for natural insect predators like wasps, lacewings, and ladybird beetles, which have reduced the need for pesticides 80 percent from the levels used in the 1990s. The hedgerows at the ends of the fields are planted with perennial grasses, blackberries, and six types of native willows, providing food and shelter for a wide variety of birds and roosting areas for raptors like barn owls and hawks, which eat up to 50 pounds of rodent pests per bird every year. Sophisticated electrostatic sprayers using natural oils and soaps provide emergency pest control when necessary.

All the Montrose's soils are intensively monitored for water content with soil moisture sensors planted throughout their fields hooked up to the farm's central water computer system and controlled at the farmhouse. All trees are watered with precise, cost-effective drip-irrigation techniques developed in Israel and perfected in California. The computer system also monitors climatic conditions at several points on the farm and has a permanent link with the agricultural weather forecast system in Sacramento, which in turn is directly linked to the international satellite weather monitoring system. The farm's computer thus makes daily decisions on an irrigation schedule, depending on soil moisture, requirements of specific crops, and current and projected climatic conditions. The farm computer coordinates watering needs with the central irrigation computer of the local irrigation district, which assembles water requirements for all the farms in the region and manages the district's overall water demands. Supplementary groundwater pumping, also carefully monitored, is also coordinated with neighboring farms utilizing the same aquifer.

A twenty-acre plot of land along a creek on the southern margin of their farm, which had always been hard to cultivate, has been set aside for wildlife such as quail, deer, and ducks. Improvements included cleaning out the creek bed (where they found an old 1982 tractor engine, a rusty bed, sixteen tires, which they recycled, and three batteries from the gasoline-powered cars of the time), planting willows, oaks, and other native plants, and digging a small pond. The creek bed and pond provide habitat for wildlife, and farm workers enjoy sitting here during breaks.

**Table 2**
**Urban California: 2020 Vision**

| | 1990 DWR[a] | 2020 DWR[a] | 2020 Vision[b] | Net Change 1990 to Vision | Percent Change 1990 to Vision |
|---|---|---|---|---|---|
| California Population (millions) | 30.0 | 48.9 | 48.9 | 18.9 | 63% |
| Total Applied Urban Water Use (million acre-feet) | 7.8 | 12.5[c] | 8.2 | 0.4 | 5% |
| Per-capita Residential Applied Water Use (gallons per person per day) | 137 | 136 | 74 | -63. | -46% |
| Total Residential Applied Water Use (million acre-feet) | 4.6 | 7.4 | 4.1 | -0.6 | -12% |
| Total Non-Residential Applied Water Use (million acre-feet) | 3.2 | 5.1 | 4.1 | 0.9 | 29% |
| Reclaimed Water Use (million acre-feet) | 0.4 | 1.3 | 2.0 | 1.6 | 400% |

[a] *All DWR numbers are derived from DWR 1994a.*

[b] *Details of the 2020 Vision can be found in Section 5A.*

[c] *DWR 2020 estimates of urban applied water use vary from 12.5 to 12.7 million acre-feet (DWR 1994a).*

## B. URBAN RENEWAL

California's population, the largest in the United States and on a par with South Korea, Italy, Great Britain, and France, was already highly urbanized in the 1990s and remains so today. Over 90 percent of the population lives in urban areas, but per-capita urban water use has dropped dramatically from 1990 due to changes in technology, social values, lifestyle, and economics. These changes began in the mid-1980s during the severest drought of the 20th century. At that time, changes in landscaping techniques, residential and municipal irrigation technology, and indoor water use temporarily mitigated water shortages. Eventually, these temporary fixes began to lead to permanent changes in preferences for landscaping and in new demand for efficient indoor fixtures. After 1990, growing interest in water-efficient technologies led to new products and markets domestically and abroad.

**Table 3**
**1990 and 2020 Residential Per-Capita Water Use, by End-Use**

| | 1990 DWR Applied Water Use[a] (gallons per person per day) | 2020 Vision Applied Water Use[b] (gallons per person per day) |
|---|---|---|
| Total Applied Indoor Water Use | 91 | 51 |
| Toilets | 33 | 8 |
| Showers/Baths | 26 | 12 |
| Faucets | 12 | 10 |
| Washing Machines | 18 | 18 |
| Dishwasher | 3 | 3 |
| Total Applied Outdoor Water Use | 46 | 23 |
| **Total Residential Applied Water Use** | **137** | **74** |

[a] *The 1990 indoor estimates are based on DWR's 1990 distribution of residential indoor water use and the statewide per-capita applied water use of 137 gallons per day. Numbers may not add up to totals due to rounding.*

[b] *The 2020 indoor water-use estimates assume an average of 5.0 toilet flushes, 4.8 minute showering time, and 4.0 minute faucet-use time daily per person. These factors are based on findings from the U.S. HUD (1994) study and have been widely used and accepted by water researchers and planners. These indoor estimates do not include efficiency improvements in non-National Energy Policy Act (1992) water-using fixtures and appliances, such as washing machines and dishwashers. The 2020 outdoor water-use estimate assumes a 25 percent reduction in outdoor potable water use and a further 25 percent substitution of outdoor potable water use with reclaimed water*

California industries now have a healthy share of the global market for water-efficiency equipment, and California water experts are regularly sought after for advice on modifying industrial processes and water policies.

Concern over equitable access to a minimum supply of clean water for all residents led the state legislature to guarantee access to 75 liters of potable water per person per day (approximately 20 gallons per person per day) at lifeline rates. This quantity includes the water needed to maintain basic human health, adequate sanitation services, and provide for minimum food preparation and cleaning. These data are comparable to the recommended standards of the United Nations International Drinking Water Supply and Sanitation Decade and the World Health Organization. For a population of 49 million people, this allocation requires about 1.1 million acre-feet per year (1.3 cubic kilometers per year). Water use for residential purposes above this minimum is now charged in increasing block rates, and all water use is metered.

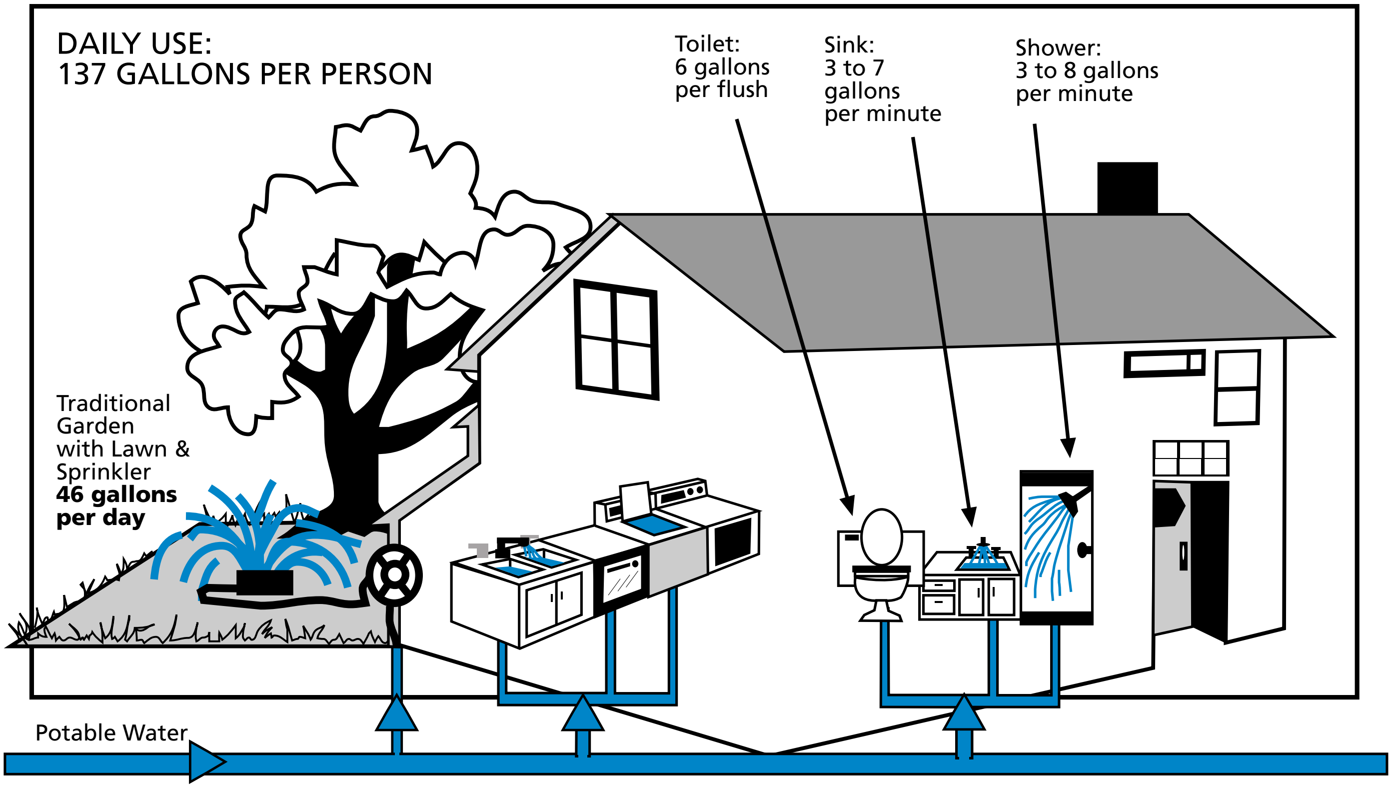
Most of the older water-using infrastructure has been replaced in residential, commercial, and municipal buildings, encouraged by state and federal policies, new standards for construction, and by water utility programs promoting replacement of fixtures in older buildings. All water fixtures meet or exceed the requirements set under the 1992 National Energy Policy Act (NEPAct). Residential per-capita indoor water use has dropped dramatically, nearly 44 percent, as a result.

Savings in per-capita water use also resulted from reductions in outdoor water use. Water-hungry grass has disappeared except where water users are willing to pay premium rates or use reclaimed water. Overall, per-capita outdoor water use is 25 percent below 1990 levels, with another 25 percent of outdoor use being satisfied by non-potable water sources. In many places, most residential and municipal landscaping has shifted to the use of native, low-water using vegetation — xeriscaping — eliminating the need for nearly all lawn irrigation. The shift to natural vegetation is driven in part by new progressive rate structures for residential and municipal water use and by educational programs emphasizing the beauty of native, drought-resistant plants. In the residential sector, some households have chosen to keep traditional lawns, but they meet this outdoor water demand with "gray" water, or they pay very high rates for using potable water. Within city limits, almost all remaining municipal or commercial outdoor turf irrigation makes use of reclaimed water rather than potable water. The use of drinking water to irrigate urban municipal and commercial landscaping has now been practically eliminated. Table 2 summarizes these changes.

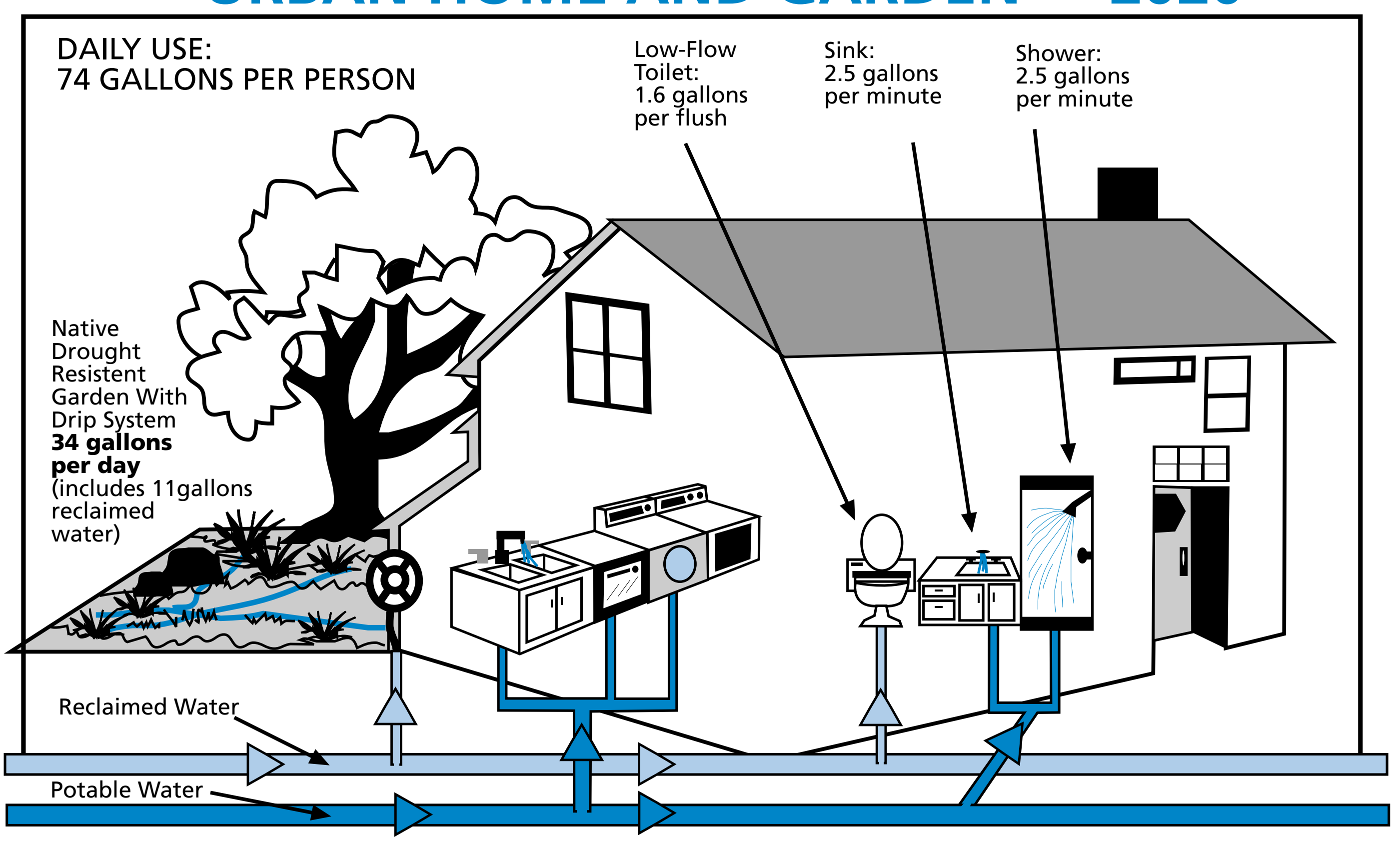
Beginning in the late 1990s, a concerted effort was started to build the infrastructure necessary to eliminate the discharge of treated wastewater into the ocean. Reclaimed water is now used for a wide range of industrial, agricultural, and commercial purposes, and meets strict health and safety standards. All new housing and all industries capable of using such water within 10 miles of a waste-treatment plant are now served by dual piping from those plants. This water source now supplies more than 2 million acre-feet of water demand in the urban and agricultural sectors, and 75 percent of all urban wastewater in California is reclaimed and reused. These efforts compare favorably with Israel, which reached 70 percent reclamation of urban wastewater in 1990 and nearly 80 percent by 2000. The city of Phoenix, Arizona met its goal of reclaiming 80 percent of its wastewater after the turn of the century, while the state of Nevada reuses 80 percent of urban wastewater for agriculture and landscape irrigation, environmental enhancement, and industrial use. The use of wastewater is encouraged by a range of tools, including low-interest loans to facilitate the construction of dual-distribution piping systems that deliver both potable and reclaimed water to users. Financial incentives to users are also available to reduce the costs of delivered water.

Total per-capita residential water use has dropped 46 percent from 1990 levels. Thus, while California's population has increased by more than 60 percent since 1990, total residential potable water demand actually decreases by 11 percent. Table 3 provides residential per-capita water use data for 1990 and 2020.

## URBAN HOME AND GARDEN - 1990




## URBAN HOME AND GARDEN - 2020



## The Urban Residence of 2020

Kathy and Jim Chien live with their nine-year old daughter in a single-family home in a suburban community between Los Angeles and San Diego. Both work at home on flexible schedules: Kathy commutes two days a week to her job as telecommunications coordinator for an industrial firm specializing in the production of components for electric buses; Jim commutes on an irregular basis to the local state community college where he manages the on-line data base for the history department. Their house is 1400 square feet and was built ten years earlier in 2010 with the best water and energy savings technology then available. In addition, they have one-quarter of an acre of property, on which they have a small vegetable garden and a place to sit and enjoy the sun.

The two bathrooms are equipped with low-flow toilets and water-efficient showers and faucets with both manual and automatic shutoff modes. The kitchen has a new dishwasher (the latest Westingtagmore), which is even more water efficient than its predecessor. The laundry room also boasts a new horizontal-axis washing machine that uses half of the water of the old machine, which was a hand-me-down from Kathy's parents. The microwave clothes drier recycles water back to the washing machine.

The drains from all the sinks and showers have automatic sensors that direct lightly soiled "graywater" to a storage system in the basement and heavily soiled water to the community sewage system. The graywater is filtered and mixed with reclaimed water from the regional waste treatment plant fed by the independent piping system recently installed for all municipal irrigation in their community. This system provides water for the nearby park, playing fields, and community gardens. Graywater is used to supply the Chien's toilets and outdoor irrigation system. Their backyard garden consists of a wide variety of native, drought-resistant plants, which attract hummingbirds and butterflies throughout the year, though Jim insists on maintaining a small area of lawn, which is also watered with reclaimed water.

Like all the residents in their community, the Chiens receive a water bill every two months, broken into three parts: their potable water use, their reclaimed water use, billed at a lower rate, and their sewerage bill, which depends on the volume of water they return to the regional water treatment plant. All water flows into and out of the house are monitored by meters that can be read directly by the water utility and that also feed directly into the home computer so that water use can be tracked by the family. Their daughter recently brought a printout of the family's water use to school to compare with other students for "Water Week." The potable water bill includes an allocation of 20 gallons per person billed at low "lifeline" rates; their water use above that amount is billed at increasing block rates. The Chien's per-capita water use is typically under 80 gallons per day, well below the average daily use of their parents — 140 gallons per person — in the 1990s.

## C. ENVIRONMENTAL REVIVAL

In 2015, state water-quality managers announced that the "Drinkable Streams" program, instituted in the year 2000 to clean up California's mountain waters was succeeding, and that new land-use standards had restored all streams and lakes in the Sierra Nevada above 7500 feet to a drinkable condition without treatment. The waters in California's Wild and Scenic Rivers System continue to be protected by law and public sentiment. Institutional mechanisms for maintaining the health of the San Francisco Bay/Delta and inland wetlands, which started to be put in place in the mid-1990s, have been further developed and implemented. Rather than reserving absolute amounts of water for ecosystems, specific ecosystem goals have been defined, such as restoring and maintaining healthy populations of freshwater and anadromous fish, keeping salinity below certain levels, and protecting habitat for waterfowl in coastal and inland wetlands. The actual amount of fresh water required to meet these goals depends on climatic conditions, the time of year, and the explicit biological goals defined. As a result of these actions, the anadromous fish populations in California's rivers that managed to survive to the turn of the century remain healthy.

These innovative approaches to balancing environmental protection with water conditions are attracting worldwide attention. Hydrological and biological experts from around the world come to California to study pristine and restored river systems and wetlands with the goal of returning and restoring damaged aquatic ecosystems at home, particularly in Europe and Asia. The recreational value of these systems, for fishing, rafting, bird-watching, and camping continues to rise, with careful management to prevent overuse.

Innovative solutions to the environmental-urban-agricultural water conflicts of the late 20th century included careful water marketing and transfers that permitted the environment to benefit from agricultural and urban water exchanges. At the same time, explicit discussion of desired ecosystem values permitted the environment/agricultural competition to be resolved and institutions to be set up to manage the water needs of both communities. These policy tools are also of interest to water experts from around the world, particularly in the Middle East, where new water-sharing arrangements are being put in place from Turkey all the way to the Sudan and the Horn of Africa.

Integrated management to protect water for the environment has led by 2020 to the restoration of some of the native fish runs in the Sacramento/San Joaquin river basins. Waterfowl populations along the Pacific Coast Flyway, which reached their nadir in the early 1990s have increased to significantly higher levels because of efforts to restore and protect seasonal habitats. Every year tourists come to see the spectacle of millions of ducks, geese, and cranes wintering in the refuges of central and northern California.

A final "fix" to the Bay/Delta system — involving both technical and institutional changes — protects vulnerable aquatic species at certain times of the year. Some levees protecting low-lying Delta islands failed during recent flood years (the result of both high runoff and some sea-level rise). Federal and state financing for levee repair and restoration was limited by economic considerations and environmental constraints, forcing innovative management. As a result, certain levees were intentionally left unrepaired, altering the flow dynamics in the Delta and improving the ecosystem health of the entire system. At the same time, the Delta fix permits better control over freshwater diversions to southern California and Central Valley agricultural communities. During extremely dry years, additional natural flows into the Delta are permitted for environmental reasons, while modest amounts of high-quality water for southern California are provided by emergency transport of water in bags towed from the Pacific Northwest and Alaska to water-supply intakes in the Delta. Similar bag technology routinely services dry coastal areas in the Middle East and drought-stricken parts of industrial Asia.

The early successes in combining wildlife habitat with rice farming is expanded to other crops and other environmental problems. Cover cropping, hedgerows, and the restoration of riparian habitat have proven especially effective at improving wildlife habitat and fishery conditions. Many farmers now compete among themselves to identify ecologically sensitive farming methods while maintaining production and revenues.

## D. INDUSTRIAL INNOVATION

In an attempt to maintain the economic health of the state, a major effort at the end of the 1990s and into the early 2000s shifted the focus of California's economic activity from military, machinery, and traditional industrial production to telecommunications, electronics, and services. This effort accelerated the changes experienced between 1970 and 1995, when major industries such as the fabricated metals, petroleum, and primary metals sectors became far less important parts of the California economy, while computer equipment, scientific instruments, and clothing manufacturing became relatively more important. After the turn of the century, this trend accelerated, and by 2020, the water-intensive industrial activities of the chemical and primary metals industries, paper and pulp production, and petroleum refining have become an even smaller fraction of the state's total economy. This has been paralleled by a substantial expansion in less water-intensive computer and telecommunication production and services, the production of transportation equipment, including alternative individual and mass-transit vehicles, and a wide range of service industries.

These industries use far less water per unit of economic output. Even the remaining water-intensive industries have substantially improved their water productivity, matching gains of the 1970s and 1980s, when total state economic output far outpaced growth in industrial water use. As a result of these trends, overall industrial water-use efficiency has increased by 20 percent over the last 25 years. These advances have also stimulated a new industry in exporting water-efficiency products and services internationally, particularly to the new Middle East/Persian Gulf confederations, to parts of Africa, and to the Indo-Asian region.

There is now a far greater use of reclaimed water for all industrial processes capable of replacing potable water. In the 1990s, rising water prices, reliability concerns, growing availability of reclaimed water, and an ethic of water efficiency all contributed to a search for the best approaches for integrating reclaimed water into the industrial process. Today, the use of reclaimed water is an integral part of California's industrial sector.

## E. FREEDOM OF INFORMATION

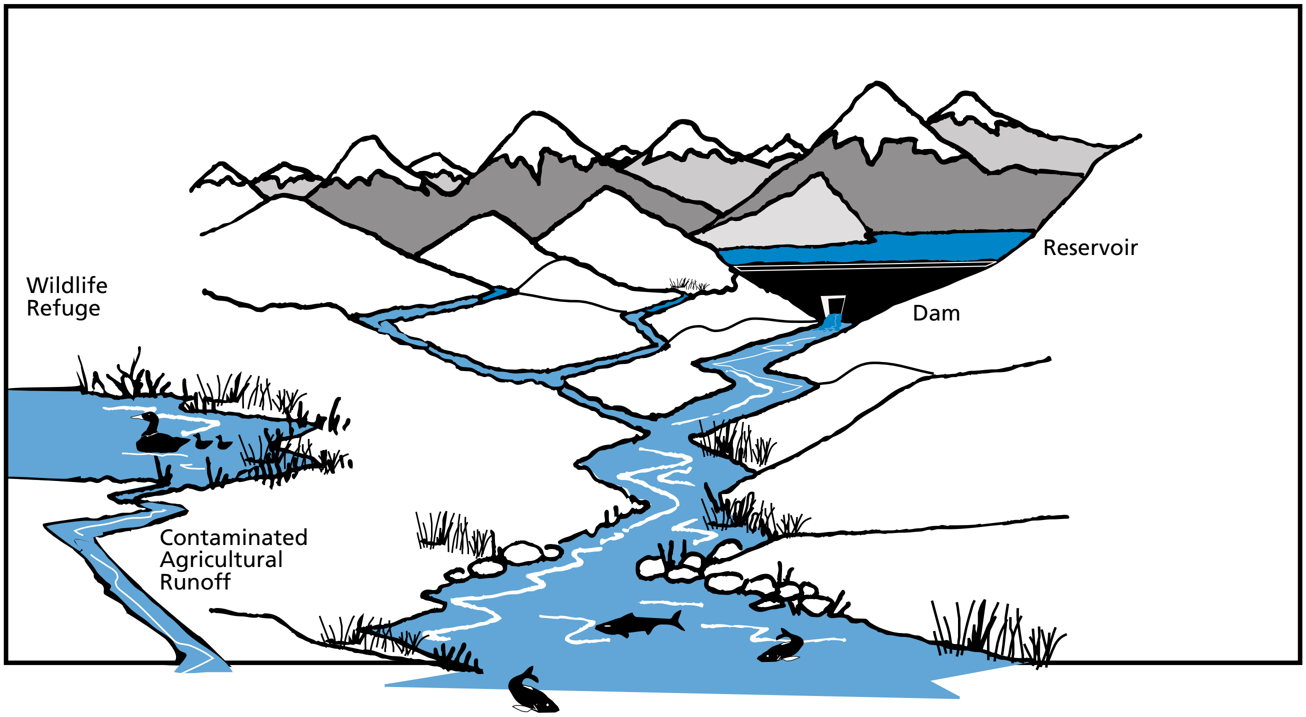
Beginning after the turn of the century, an all-out effort was made to put into place an effective and inexpensive system for collecting, evaluating, and archiving California water-resources data. In large part, this effort was stimulated by the realization that inadequate information on state water resources and use was seriously hindering the development of rational, long-term water plans. But the decision to improve data collection and management was also accelerated by the development of sophisticated computer networks, data management methods, inexpensive accurate monitoring technology, and growing demands for water data by diverse users.

Today, data on all aspects of water stocks, flows, use, and quality are being collected. Using new, flexible orbiting earth-observing stations, precipitation, evapotranspiration, vegetative cover, land use, soil moisture, the Sierra Nevada snowpack, surface water quality, and other important variables are now routinely monitored. On the ground, all aspects of human water use are closely measured, including groundwater pumping and recharge rates, volumes of flow, and quality. These data are freely and easily available to the public, often in real time, through the Net and supported by a consortium including a newly formed state independent water agency, California academic organizations, and non-governmental groups.

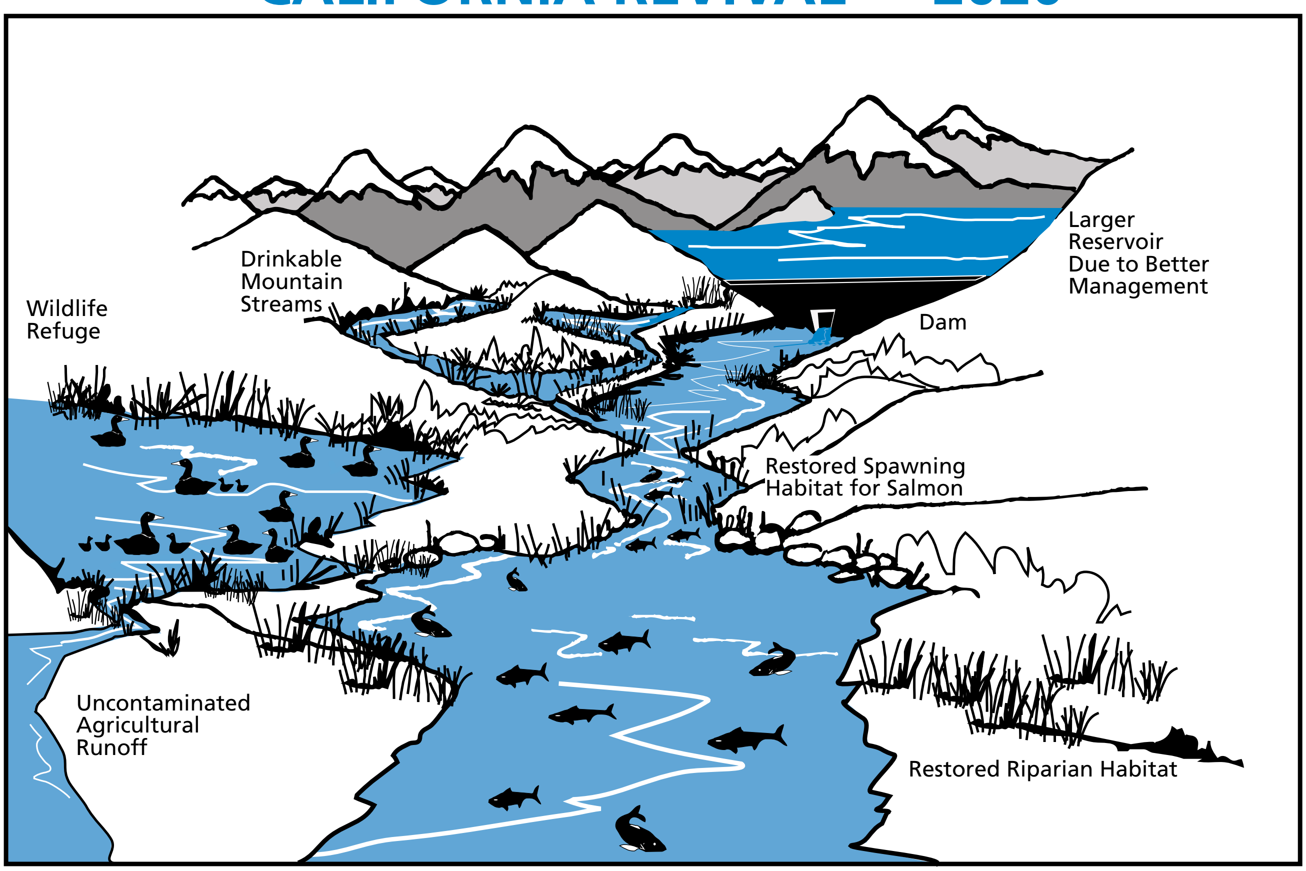
## F. INSTITUTIONAL RE-ORGANIZATION

Leading the way towards these changes in California water policy and planning in 2020 is a restructured and revitalized water

## CALIFORNIA ENVIRONMENT - 1990




## CALIFORNIA REVIVAL - 2020



## The Sacramento-San Joaquin Valley of 2020

The Great Central Valley of California, a 430-mile long and 75-mile wide depression between the Coast Ranges and the Sierra Nevada, is home to California's important agricultural areas, rich migratory waterfowl refuges, and an increasing fraction of the state's population of nearly 50 million people. The process of urban sprawl, begun in the middle of the 20th century, has continued during the first two decades of the 21st century, though efforts have been made to constrain development in areas of prime farmland. As a result, the land between San Francisco Bay and the Sierra Nevada foothills that included Vacaville, Sacramento, and Auburn has become a continuous urban corridor bisecting the Valley. This corridor is served by regular high-speed electric trains along the old I-80 route.

In the Valley itself, major urban developments are also present around Modesto, Fresno, and Bakersfield, though strong rural agricultural communities remain firmly in place. The northern Sacramento Valley continues to grow almonds, new varieties of tomatoes and rice, irrigated pasture and other field and truck crops. The southern portion — the San Joaquin and Tulare basins — continues to grow high-yield cotton, truck crops, almonds and other high-valued nuts, and grapes. Throughout the Central Valley there has been a shift away from water-intensive field crops such as alfalfa, irrigated pasture, cotton, and rice, though these still make up a large fraction of California's irrigated acreage. Certain marginal lands brought under irrigation in the 1960, '70s, and '80s have been taken out of production and replanted with native vegetation in an effort to improve groundwater quality and restore some of the original grassland habitat. Perennial bunchgrasses and annual grasses and herbs have been planted on some of this land, reviving the legendary wildflower displays and drawing visitors from throughout the country. Plans are underway to reintroduce populations of Tule Elk, Pronghorn, and Mule Deer into selected reconstructed prairie habitats.

Hundreds of scientific experts from around the world come annually to study the success of Wild and Scenic Rivers legislation and other actions to protect California's aquatic ecosystems. Growing interest in restoring damaged river systems elsewhere, particularly in Europe and Asia, has focused new attention on California's methods and experience in managing relatively pristine waterways.

Integrated management to protect water for the environment has led to the restoration of some of the native fish runs in the Sacramento/San Joaquin river basins. The other anadromous fish populations in California's rivers that managed to survive to the turn of the century remain healthy, though more than 30 of California's original naturally spawning Pacific salmon stocks are gone for good.

Waterfowl populations along the Pacific Coast Flyway, which dropped from an estimated 60 million in the 1940s to 3 million in 1993 have increased to nearly 15 million because of efforts to restore and protect seasonal habitats. Every year thousands of out-of-state visitors flock to see the spectacle of millions of waterfowl wintering in the refuges of central and northern California and many farmers compete to see who can attract the most rare bird species (and income-generating bird-watching tourists) to their communities during migrations.

Major floods in the early part of the century — a combination of climate-induced sea-level rise and severe storms — caused the failure of some levees in the Delta and the flooding of several low-lying Delta islands. Lack of financing and new state policies prevented complete rebuilding of the levee system. Instead, selective levees were reconstructed to alter the flow dynamics in the Delta to improve the ecosystem health of the entire system and to reduce the risk of salt water contaminating fresh water intakes. At the same time, the Delta fix permits better control over freshwater diversions to southern California and Central Valley agricultural communities and has helped restore and sustain threatened fisheries.

planning institution. By the turn of the century, water planners came to accept that planning was more than a technical exercise for engineers to carry out behind closed doors. Today, planning is viewed as an exercise in the democratic control of water resources, with broad public participation and open access to information. The official California Water Plan is now produced under the guidance of a new statewide planning agency independent of the state agency responsible for construction and operation of supply projects. The new agency was created as a planning group, a clearinghouse for water-resource data, an educational resource for water users, and a forum for resolving conflicts over water when it became clear that existing organizations were ill-suited for these tasks.

The employees of the new agency have a wide range of skills, including training in policy, law, irrigation technology, hydrology, economics, ecology, sociology, biology, and engineering. The agency coordinates with other federal and state agencies as well as local water districts, agricultural and industrial users, and environmental interests in the construction of the state water plan. It maintains strong relationships with non-governmental organizations to help collect information and enforce monitoring of water use. By working with both these governmental and non-governmental organizations, the planning agency gathers information and develops operational plans much more effectively and efficiently.

Today, the official California Water Plan includes visions of long-term water supply and use to 2050 and 2075, and guides long-term water policy. To fashion these visions, the agency builds a forum of water interests. In particular, the agency seeks out groups that were traditionally underrepresented during the end of the last century. It provides resources to disenfranchised groups to help them participate on an equal basis with better organized and wealthier groups. Consensus and conflict resolution techniques are used to find common ground among competing interests. In cases where sufficient consensus on the future vision is not possible in a timely manner, alternative visions are now explored and choices presented for the state legislature to decide.

Besides building consensus, one of the agency's chief tasks is compiling and making accessible water data. To provide necessary information, the agency has developed and implemented surface and groundwater monitoring programs statewide that coordinate with federal and international data-gathering satellites and ground-based projects. Furthermore, in cooperation with fish and wildlife organizations and environmental groups, it developed and maintains a database on water quality and water requirements for ecosystem health. Groups use this information to educate the public, assist water users to become more water efficient, and provide various interest groups with information for planning. Data are organized and available through a variety of electronic means and are freely accessible through public libraries, schools, and direct telecommunications.

## G. STRATEGIC OPTIONS FOR REACHING A SUSTAINABLE WATER FUTURE

The vision presented in the preceding pages offers possible directions for California water interests. How can California reach this vision? The broad outlines of how to proceed toward a sustainable water future are already known. The institutional and financial tools to shift in these directions are, for the most part, little different from those already available or working in California or elsewhere. Described briefly here are strategic options for moving in the direction presented above.

### 1. Agricultural Transformation

The major changes laid out in the agricultural vision over the next 25 years entail changes in the types of farms and farming communities, and shifts in crop types away from low-valued, highly water consumptive crops. In particular, irrigated pasture, alfalfa, rice, and cotton generate only modest amounts of farm revenue per unit of water applied compared to the vegetable and fruit crops for which California is renown. Over time, incremental shifts away from these water-intensive crops can effectively reduce agricultural water demands with possible gains in farm income and employment.

Many factors influence the crops farmers choose to grow. They include soil types, market prices for crops, government agricultural subsidies, experience and knowledge, water availability and prices, family tradition, equipment costs, and so on. The changes projected here as desirable over 30 years (between 1990 and 2020) are not particularly dramatic — they are intentionally comparable to the kinds and magnitude of changes experienced in California agriculture over the *last* 30 years. As a result, if policymakers and the public conclude that these changes are an appropriate goal, different combinations of policies could be put into place to encourage them. Among the most important changes needed to move water policies toward sustainable agriculture are to:

- Design and implement comprehensive local groundwater monitoring and management programs statewide.
- Gradually reduce federal and state water subsidies that encourage inefficient use of water.
- Gradually reduce federal and state crop subsidies for low-value, water-intensive crops.
- Develop on-line data collection and dissemination networks to provide farmers with immediate meteorological and hydrological information on climate, soil conditions, and crop water needs.
- Implement programs for permitting water transfers and marketing.
- Identify and reduce adverse impacts on rural communities and the environment from higher water costs or water transfers.
- Identify and improve upon agricultural practices that enhance environmental values.
- Continue experimentation, commercial development, and use of efficient irrigation technologies, new crop types, and non-chemical agricultural practices.
- Implement new rate structures at local, state, and federal levels to encourage more efficient use of water.
- Identify and protect strategic farmland from urban development.

## 2. Urban Renewal

The urban vision described here results from three major changes: improvements in indoor water efficiencies, reductions in outdoor water use, and greater use of reclaimed water where appropriate. No dramatic changes in lifestyle are assumed here; what is projected instead is maintaining current standards of living while reducing the water requirements of those choices, and providing a minimum standard for all California residents.

Improvements in the industrial sector are also likely to continue recent trends, but will involve more attention by specific industrial users. Changes in the structure of the industrial sector, away from certain water-intensive activities of heavy industry toward industries that require little water per unit of output, may prove to be as or more effective than efficiency improvements within sectors. Present indications are that both trends will persist. General strategic options for the urban sector include:

- Fully implement existing water-efficiency provisions of the 1992 National Energy Policy Act.
- Develop new cost-effective water-savings equipment and methods for indoor and outdoor residential, commercial, and industrial water use.
- Develop programs to encourage implementation and use of water-efficient technologies and practices.
- Implement lifeline water allocations and rates for the residential sector.
- Implement increasing block pricing or other innovative rate structures for all urban users.
- Develop programs to evaluate applicability of reclaimed wastewater for different uses.
- Develop programs to encourage appropriate use of reclaimed wastewater.

## 3. Environmental Revival

Environmental protection has not always been an important component of California's political landscape. In recent years, however, it has become clear that the public wants to protect much of what remains of the natural heritage of the region. Balancing this protection with the resource demands of the same public is a major challenge. By 2020, many of the disputes over protecting environmental goods and services could be resolved. Among the strategic options for meeting this goal are to:

- Implement programs to permit participation of the environmental sector in water markets and trades.
- Identify and set flexible water requirements for restoring and maintaining specific environmental goals.
- Integrate agricultural and environmental water management in the Sacramento and San Joaquin Valleys, where the best agricultural land and vitally important environmental resources co-exist.
- Integrate land-use and water-supply planning for new development in urban areas.
- Design river flow and quality regimes that protect and enhance remaining anadromous fish populations.
- Collect and maintain environmental and ecological data, with open access.

# II. California Water Planning: The Need For A New Vision

## A. INTRODUCTION

The management and protection of California's freshwater resources have reached a crucial period. In the last decade, it has become obvious to many that traditional water policies, which permitted California to become the agricultural and economic force it is today, are not up to the task of meeting the challenges of the 21st century. Yet water institutions and policymakers have so far been unable to develop new tools and approaches to try to understand and address the nature of these new challenges.

Two trends exemplify the deadlock now gripping California water management: the conflict between urban, agricultural, and environmental water interests, and the inability of competing parties to agree upon adequate standards of protection for groundwater aquifers, Central Valley water resources, and critical aquatic ecosystems, such as the Bay/Delta system. The traditional response to past water problems was to build major new facilities, but this option is rapidly closing because of federal and state budget problems and the perception that such facilities often cause more problems than they solve. Yet efforts to explore nonstructural alternatives have not been encouraged. Ironically, after seven years of drought in the past eight years, the limited state funding available for water conservation efforts is being reduced. According to some estimates, official 1994 funding for the water conservation office was about $2 million out of a total Department of Water Resources (DWR) budget of nearly $1 billion. And that is half of what it was when the drought began in 1987 (Mayer 1994). Even the official DWR budget shows the 1994-95 overall conservation funding at only 0.33 percent of their total budget (J. Florez, DWR, Budget Office, personal communication, 1995). As a result, California water policy is so hobbled and confused that it offers no reasonable guidance for the future, which may also include such complications as large-scale climatic changes, rapid population growth in the most water-short regions, and important, but uncertain technological and institutional changes.

Sound water policy for the 21st century will require solid planning. Currently, there is no consensus on how society should be using its limited freshwater supply. There are only conflicts and litigation over every new proposed policy. What is needed for the coming decades is a planning process that will resolve water conflicts by setting new goals and priorities for water-resource management.

## B. TWENTIETH CENTURY WATER PLANNING: THE STATUS QUO

During the 20th century, water-resources planning has typically focused on making projections of variables such as future populations, per-capita water demand, agricultural production, levels of economic productivity, and so on. These projections are then used to predict future water demands and to evaluate the kind of systems necessary to meet those demands reliably. As a result, traditional water planning always projects future water demands independent of, and typically larger than, actual water availability. Planning then consists of suggestions of alternative ways of bridging this apparent gap between demand and supply. Prior to 1980, these exercises resulted in a focus on supply-side solutions: it was assumed that the projected shortfalls would be met solely by building more physical infrastructure, usually reservoirs for water storage or new aqueducts and pipelines for interbasin transfers. In recent years, some water suppliers and planning agencies have begun to explore limited demand-side management and improvements in water-use efficiency as a

***What is needed for the coming decades is a planning process that will resolve water conflicts by setting new goals and priorities for water-resource management.***

means of reducing the projected gaps. While this is certainly an improvement, traditional planning approaches and a reliance on traditional solutions continue to dominate water management actions.

The present method for projecting water demands assumes that future societal structures and desires are virtually identical to those in place today. Resource, environmental, or economic constraints are not considered. Even ignoring the difficulty of projecting future populations and levels of economic activities, there are many limitations to this approach. Perhaps the greatest problem is that it routinely produces scenarios with irrational conclusions, such as water demand exceeding supply and water withdrawals unconstrained by environmental or ecological limits.

*A major problem afflicting California water planning is the failure to set priorities and values. The current lack of consensus on a guiding ethic for water policy has led to fragmented decision-making and incremental changes that satisfy no one.*

California water management is a good example. Every several years, the California Department of Water Resources (DWR) issues its update to the "California Water Plan."[1] The most recent version, officially released in late 1994, could have been an opportunity to look forward toward alternative approaches to the state's water problems. Instead, it is little different in the nature of its projections and proposed solutions from the plans developed over the past 35 years.

According to the DWR, California water policies — and problems — in 2020 will be little changed from today. The state will grow the same kinds of crops, on about the same amount of land. The larger urban population will slightly improve water-use efficiency, but large amounts of water will still go for household and municipal lawns. Many groundwater aquifers will still be pumped faster than they are replenished. Billions of gallons of treated wastewater will be dumped into the oceans, rather than recycled and reused where appropriate. Water needed to maintain threatened California ecosystems and aquatic species will come and go with the rains and with human demands. And projections of total water demands exceed available supplies by several million acre-feet — a shortfall projected in every report since 1957. Figure 3 shows water supply and demand as projected for the year 2020 by several of the official water plans.

Trend is not destiny, and projections are not predictions. Yet there is little reason for optimism to observers of the California water scene. Endless hearings over standards to protect the San Francisco Bay and the Sacramento/San Joaquin Delta have been ordered, and held, and canceled, and rescheduled.[2] Policy decisions on important issues have been proposed and rejected and redrafted and re-rejected because competing interests cannot, or will not, agree. As a result, vulnerable agricultural communities, fisheries and the people that depend on them, and urban and industrial users all suffer from inaction today.

A major problem afflicting California water planning is the failure to set priorities and values for the use of water. The current lack of consensus on a guiding ethic for water policy has led to fragmented decision-making and incremental changes that satisfy no one. Some suggest that the problem is primarily technical and that we only need more efficient technology and better benefit-cost analyses to satisfy the needs of all interests involved. Others believe that only a reorganization and coordination of the state's now fragmented policy process will rationalize water policy.

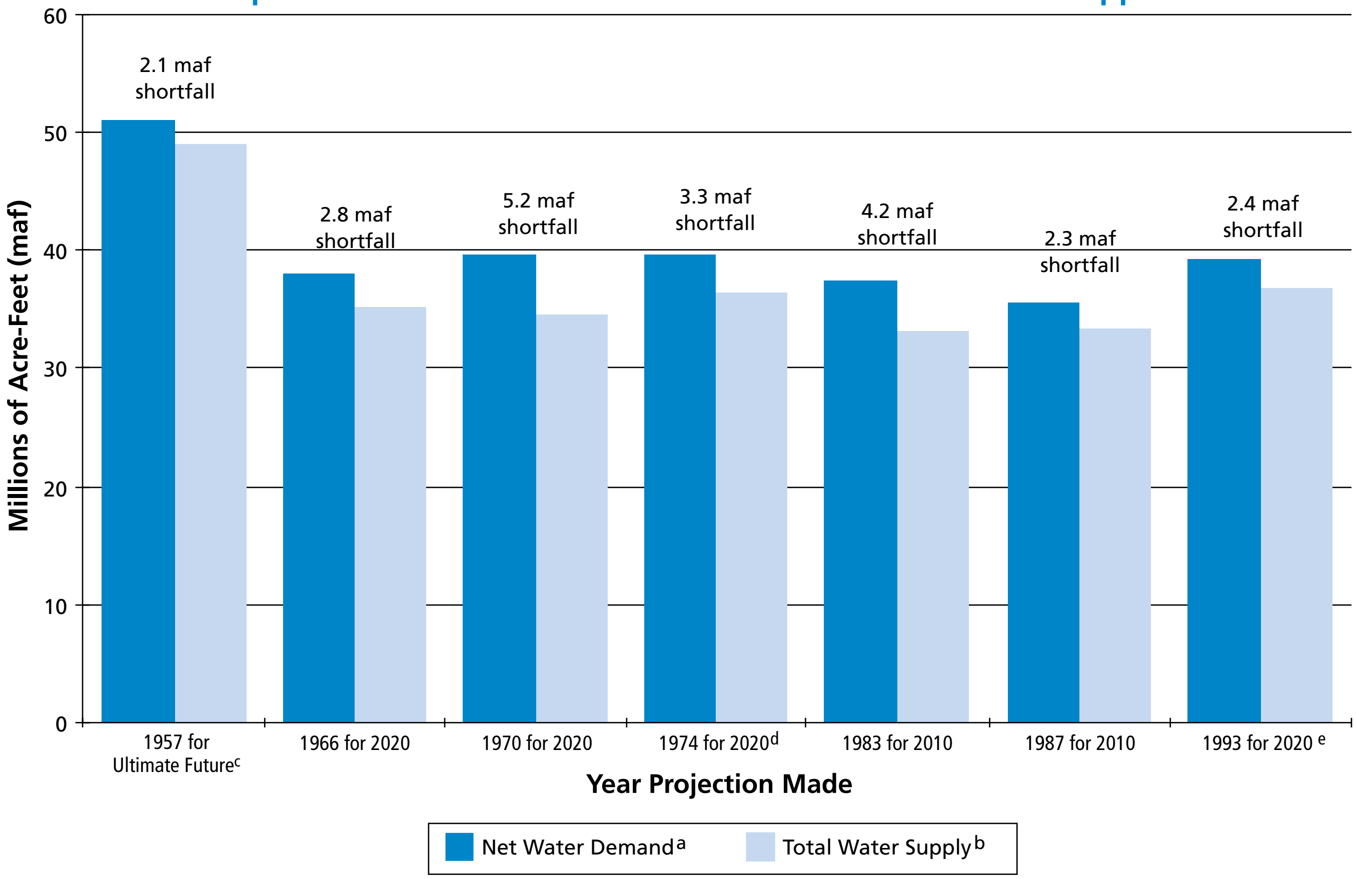
## C. TWENTY-FIRST CENTURY WATER PLANNING: THE NEED FOR A NEW VISION

This report begins with the premise that current water planning in California represents a failure of water-resource institutions to forge common goals for water development and to seek agreement on principles to resolve conflicts over water. The twentieth-century

[1] The original California Water Plan was published in 1957 as Bulletin 3. Now officially known as Bulletin 160, updates to the California Water Plan have been published in 1966, 1970, 1974, 1983, 1987, and, most recently, 1993 (with an official final report release in the fall of 1994).

[2] In December 1994, a new interim decision on standards and procedures to protect the San Francisco Bay/Delta was announced by the federal, state, and non-governmental groups responsible for reaching a decision. Despite remaining uncertainties, there is hope that this issue may at last be largely resolved.

**Figure 3**
**Comparison of DWR Forecasts of Net Water Demands and Supplies**




*[a] Net Water Demand includes urban, agricultural, and wildlife/recreation/other except in the 1966 projection which includes only agricultural and urban needs.*
*[b] Total Water Supply includes expected future additions at time of projection and does not include groundwater overdraft except in the 1966 projection.*
*[c] The Ultimate Future projection of 1957 is the estimated supply and demand when the state's land is in a state of full development.*
*[d] Four future scenarios were calculated in 1974. The projections here are from Future Alternative III, the most reasonable future according to the DWR.*
*[e] The official 1993 projections included undeveloped water supplies not included in previous DWR projections.*
*The supply and demand figures here exclude dedicated natural flow and instream flows.*

*Sources: DWR 1957, 1966, 1970, 1974, 1983, 1987, 1994a.*

*maf = million acre-feet*

water-development paradigm, which was driven by an ethic of growth powered by continued expansion of water-supply infrastructure, has been stalled for the last two decades as social values and political and economic conditions have changed. Meaningful change towards a new ethic has to begin with a dialogue on the ultimate ends of water-resource policy.

Sustainability and equity are primary goals from which to begin. Simply stated, these goals place a high value on maintaining the integrity of water resources and the flora, fauna, and human societies that have developed around them. And it means that the costs and benefits of water-resource management and development are to be distributed in a fair

***It is time to plan for meeting human and ecological needs with the water that is available, and to determine what desires can be satisfied within the limits of our resources. This is an essential change, and will require some new thinking at the highest levels — a hydrologic perestroika.***

and prudent manner. Together, these goals represent a commitment to nature and the diverse social groups of the present and future generations.

An ethic of sustainability will require a fundamental change in how we think about water in California. Rather than trying to find the water to meet some projection of future desires, it is time to plan for meeting present and future human and ecological needs with the water that is available, and to determine what desires can be satisfied within the limits of our resources. This is an essential change, and will require some new thinking at the highest levels — a hydrologic *perestroika*.

Water-resource planning in a democratic society requires more than simply deciding what project to build next or evaluating which scheme is the most cost-effective. Planning must provide information that helps the public to make judgments about which "needs" and "wants" can and should be satisfied. Water is a common good and community resource, but it is also used as a private good or economic commodity; it is not only a necessity for life but also a recreational resource; it is imbued with cultural values and plays a part in the social life of our communities. The principles of sustainability and equity can help bridge the gap between such diverse and competing interests.

A statewide water plan must address such questions as: How much water is needed for satisfying the domestic use of a family in urban Los Angeles or in a rural community? Should people be able to use as much water as they can pay for? Under what situations should water be delivered to farmers at rates below full operating and capital costs? How much water is needed to maintain environmental quality? What level of environmental quality is enough? How much water should be available and at what quality for the use of future generations?

***In the absence of democratic dialogue, water-resource development can only continue down a course plotted decades ago, one that may have been appropriate then, but which fails to meet the challenges of the next century.***

We present here a set of criteria for guiding water-resource management. These sustainability criteria constitute an ethic that helps prioritize competing claims over water. This ethic may be easy to state, but the real challenge is to define the specifics. What do sustainability and equity mean when applied in the real world? What kind of planning practices are consistent with these objectives?

While not all will agree with the specific approach taken here, the direction that is set out can be used to guide rational and meaningful debate over water-resource policy. Rather than allowing the overall goals to be determined by the outcomes of fights among the most powerful and wealthy interest groups, goals to further a genuine common interest can be forged and real conflicts can be resolved in a fair and equitable manner based on democratic ideals. In the absence of democratic dialogue, water-resource development can only continue down a course plotted decades ago, one that may have been appropriate then, but which fails to meet the challenges of the next century.

# III. Water And Sustainability

Ever since the Brundtland Commission Report (WCED 1987) and the 1992 Earth Summit in Rio popularized the concept of sustainability, there has been considerable confusion over exactly what the term means and how to apply it. Whether the concepts of sustainability and sustainable development will have any significant lasting effect on the real world, however, depends on their definitions. Without clear definitions, these terms will simply be short-lived buzzwords destined to fade from popular rhetoric. This section attempts to make clear exactly what we mean by sustainability and lays out seven sustainability criteria that we think can usefully guide water management and planning.

## A. SUSTAINABILITY IN CONTEXT

Sustainability has both quantitative and qualitative aspects. Like equity, sustainability can be a social goal — an end realized between people in civil society. For some, sustainability follows in the footsteps of other classic moral terms such as liberty, equality, justice, freedom, solidarity, and others. Although these moral concepts are difficult to define with mathematical precision, they form the basis of substantial public policy. These are the ideas used in public debates to define the "good" society (Bellah et al. 1991).

Sustainability, in this broad sense, is not a scientifically determinable concept. Its ultimate definition depends on public discourse and on the practices of the institutions that society creates. Scientists and planners further this public discourse by exploring the implications of different interpretations of sustainability, but science cannot say that one particular interpretation is the "correct" one for society. For example, economists have developed the gross domestic product (GDP) indicator for measuring economic welfare, but it is widely understood that GDP is not the same as social welfare and often conflicts with it in important ways. These types of measures have been used in many public policies, but are only useful to the extent that there is a political consensus on their meaning.

Some analysts have tried to reduce the concept of sustainability to a mere indicator to make it easier to measure and more amenable to public policy debates. For instance, planners for forestry and fishery resources long ago developed the concept of "sustainable yield" as a measure to help manage these resources. Other scientists have argued that single indicators are of limited usefulness since what is really important is the sustainability of whole ecosystems consisting of humans intertwined with many different species. These scientists argue that for the concept to be analytically useful, sustainability must include the concept of maintaining the benefit flows from ecological support services and natural resources (Holdren et al. 1992).

At a simple level, sustainability means maintaining something undiminished over time, including natural resource flows, ecological goods and services, and human well-being. In part, sustainability is the capability of human society to persist in a desirable way into the indefinite future, while at the same time maintaining the ecological systems necessary for human survival (Lélé 1994). More broadly, this approach would require that sustainability also include recognition of non-human values, such as the importance of other species, or ecosystems as a whole.

***Water is not only essential to sustain life, but it also plays an integral role in ecosystem support, economic development, community well-being, and cultural values.***

Another way to characterize sustainability is through the concept of justice. Sustainability involves justice among generations, species, existing social groups, and geographic regions. This broader interpretation of sustainability explicitly embodies social and individual values.

With respect to water resources, as with many other resources, sustainability has not been clearly defined. Water is not only essential to sustain life, but it also plays an integral

***We define sustainable water use as the use of water that supports the ability of human society to endure and flourish into the indefinite future without undermining the integrity of the hydrological cycle or the ecological systems that depend on it.***

role in ecosystem support, economic development, community well-being, and cultural values. How all these values, which are sometimes conflicting, are to be prioritized, which are to be sustained, and in what fashion, are questions that should be open to public debate. In this report, we define sustainable water use as *the use of water that supports the ability of human society to endure and flourish into the indefinite future without undermining the integrity of the hydrological cycle or the ecological systems that depend on it.*

## B. THE SUSTAINABILITY CRITERIA

Explicit criteria and goals for the sustainability of freshwater resources have been developed at the Pacific Institute and are presented here in Table 4. These criteria lay out human and environmental priorities for water use, taking into account not only the needs of the current populations of California (or elsewhere), but also those of future generations. Agenda 21, the United Nations Programme of Action developed at the 1992 Earth Summit, devotes a chapter to freshwater concerns (UN 1992). This "call to action" sets as immediate objectives the integration of ecosystem requirements into water-resources management, the satisfaction of basic human needs, the incorporation of rational economic approaches for human uses of water, and the design, implementation, and evaluation of sustainable water programs with both economic and social components.

The criteria and goals of Table 4 are the result of considerable dialog and analysis with academic, governmental, and non-governmental interests working on California, national, and international water problems. While these criteria will no doubt be further refined, they are presented here in the context of California water planning to help stimulate a new debate and to offer some guidance for legislative and non-governmental actions in the future. In particular, these criteria can provide the basis for an alternative "vision" for future California water management. They are not, by themselves, recommendations for actions; rather they are endpoints for policy — they lay out specific societal goals that could, or should, be attained. After the criteria are presented, the discussion turns to identifying how much water is required to satisfy these priorities and the alternative approaches for reaching these goals through economic, technical, educational, and regulatory means. While debate on how to attain these goals is unavoidable (and is even desirable), having a set of clear targets will help focus the ultimate policy decisions.

**Table 4**
**Sustainability Criteria for Water**

1. A minimum water requirement will be guaranteed to all humans to maintain human health.
2. Sufficient water will be guaranteed to restore and maintain the health of ecosystems. Specific amounts will vary depending on climatic and other conditions. Setting these amounts will require flexible and dynamic management.
3. Data on water resources availability, use, and quality will be collected and made accessible to all parties.
4. Water quality will be maintained to meet certain minimum standards. These standards will vary depending on location and how the water is to be used.
5. Human actions will not impair the long-term renewability of freshwater stocks and flows.
6. Institutional mechanisms will be set up to prevent and resolve conflicts over water.
7. Water planning and decision-making will be democratic, ensuring representation of all affected parties and fostering direct participation of affected interests.

## C. DISCUSSION OF THE CRITERIA

### 1. Minimum Human and Environmental Water Requirements

The first two criteria listed above set as primary goals the provision of a minimum amount of water for meeting the essential needs of humans and natural ecosystems. These elementary goals, common to many different interpretations of sustainability over the past few years, serve to address the "basic needs" requirements stated in the United Nations Agenda 21, explicitly recognizing the standing of both humans and ecosystems (UN 1992). For humans, insufficient access to potable water is the direct cause of millions of unnecessary deaths every year (Nash 1993a). The provision of a minimum amount of fresh water to support human metabolism and to maintain human health should be a guaranteed commitment on the part of governments and water providers. Similarly, ecosystems must be guaranteed a minimum freshwater supply to restore, maintain, and protect vital services and functions.

In the past, there has been no difficulty meeting minimum requirements for humans in California, although this criteria is already being violated in many parts of the developing world. On the other hand, minimum water requirements have rarely been defined for ecosystems, and there have been severe ecological impacts to aquatic ecosystems as a result (Gleick and Nash 1991, Nash 1993b, Thelander 1994).

The minimum amount of clean water required to maintain human health is quite low — approximately 5 gallons per person per day (20 liters per person per day) for drinking and food preparation (WHO 1971, NAS 1977). Practically all California residents have access to that amount of water. Adding minimum requirements for sanitation and cleaning raises this amount to about 20 gallons per person per day (roughly 75 liters per person per day). These minimum requirements are described in Table 5. A population of just under 49 million people — California's estimated population in 2020 — would thus require just over 1.1 million acre-feet per year (about 1.3 cubic kilometer per year) of potable water to satisfy *minimum* human health requirements. California's annual average water availability is about 70 times this amount.

**Table 5**
**Minimum Water Requirements**

| Purpose | Range (liters per person per day) | Range (gallons per person per day) |
|---|---|---|
| Drinking Water [a] | 2 to 3 | 0.5 to 0.8 |
| Cooking [c] | 15 | 4 |
| Sanitation Services [b] | under 10 to over 75 | 2.6 to 20 |
| Bathing [c] | 15 | 4 |

[a] *This is a true minimum to sustain life.*

[b] *A daily average of 10 gallons/person (40 liters/person) is considered adequate for direct sanitation hookups in industrialized countries.*

[c] *These values represent a societal minimum, not an absolute minimum, for moderately industrialized countries.*

No legal or institutional mechanism exists, however, to guarantee even this minimum requirement to present and future generations. The first criterion, therefore, guarantees access to this minimum water requirement to meet the basic health needs of the entire population of the state. As with the energy system, the minimum water requirement should be available at lifeline economic rates. This basic right to water should only be guaranteed if it is consistent with land-use and development goals; water should not be provided regardless of geographical location.

While efforts have begun in California to identify ecosystem water requirements, few legal guarantees for water have been set and there is little agreement about minimum water needs for the environment. Existing protections include preservation of stretches of several northern California rivers through the federal and state Wild and Scenic Rivers Acts, minimum flow requirements in some river stretches, recent reallocations of some water from the Central Valley Project to the environment, and new standards to protect the San Francisco Bay-Delta system.

In part due to the lack of clearly defined legal water rights, many of California's aquatic ecosystems have become severely threatened or endangered. Overall, more than 650 species of plants and animals have been recognized by the state or federal governments as threatened or endangered; 115 in California alone (DWR 1994a, Thelander 1994). In the last couple of years, several have been added to the list, including the Delta smelt and the winter-run Chinook salmon, because of increasing pressures on California's aquatic environment. Anadromous fisheries, in general, have suffered severe stress during low-flow years, such as have been experienced during seven of the past eight years (Nash 1993b).

Ultimately, minimum allocations of water for the environment will have to be made on a flexible basis, accounting for climatic variability, seasonal fluctuations, and other factors. Management will have to follow an adaptive model where decisions are to be reviewed frequently based on the latest information and caution is exercised with respect to possible irreversible actions. The ecosystems for which water will be provided include both natural ecosystems where there is a minimum of human interference and ecosystems that are highly managed by humans. Societal decisions will have to be made regarding the degree to which these ecosystems should be maintained or restored and the indicators by which to measure their health.

### 2. Data Collection and Availability

If water planning and management are to be democratic and effective, data on all aspects of the water cycle must be collected and made available in an unrestricted manner. At present, data on many aspects of California's water supply and use are not collected and when they are, are not widely available. Very few data, for example, are collected in California on the condition of different groundwater basins, extraction amounts, current pumping practices, and recharge rates. Similarly, water-use information is very sketchy or site specific, making actions for increasing efficiency or improving conservation programs hard to plan and implement. Information should be produced in reasonable time with reasonable resources, and it should be shared between groups and the state, thus enhancing the number of perspectives and detail of information available.

### 3. Water Quality Standards

Different uses require water of differing qualities. As a result, water-quality standards for different purposes must be developed, and water quality must be monitored and maintained to meet these standards. Most of California's water is protected from contamination by federal and state regulations. These water-quality standards are supposed to ensure that potable water is free from contaminants known to affect human health. At the same time, however, water used for non-human consumption need not be protected to the same standards. For example, water used for many industrial, commercial, or landscaping purposes could be protected to a lower standard, with substantial economic savings. Similar water quality criteria need to be developed for environmental water requirements. Some effort should go into identifying these differences and developing ways of meeting various demands with water at appropriate levels of quality.

### 4. Renewability of Water Resources

Freshwater resources are typically considered renewable: they can be used in a manner that does not affect the long-term availability of the same resource. There are, however, ways in which renewable freshwater resources can be made nonrenewable, including mismanagement of watersheds, overpumping, land subsidence, and aquifer contamination. Water policy should explicitly protect against these irreversible activities.

Groundwater stocks are renewable on timelines that depend upon the rate of inflow of water, the rate of withdrawals of water, and the geophysical characteristics of the aquifer. In some instances, overpumping of groundwater — the extraction of groundwater at a rate that exceeds the rate of natural recharge — can continue for some time with no adverse consequences if the aquifer is permitted to be recharged during wet periods. Thus a short-term nonrenewable use may still be compatible with long-term renewability.

Unfortunately, some forms of groundwater pumping, in some regions, lead to the irreversible decline in the ability of a region to store water in the ground. Excessive groundwater pumping in parts of the Central Valley and

*Groundwater pumps provide considerable water for California agriculture. For the most part, these pumps are not metered and groundwater use is not monitored, leading to overdraft in many regions. (Courtesy of DWR.)*

Santa Clara Valley, for example, has led to extensive land subsidence, which reduces the ability of wet years to fully recharge groundwater aquifers. Estimates are that California's Central Valley has lost over 20 million acre-feet (maf) of storage capacity due to compaction of over-exploited groundwater aquifers (Bertoldi 1992). To put this loss in perspective, the entire storage capacity of all constructed reservoirs in the state is under 50 maf (DWR 1994a). Overpumping of ground water in coastal aquifers can also lead to irreversible and unsustainable effects, including salt water intrusion and the ultimate contamination of the entire groundwater stock.

Surface waters can also be contaminated or lost through watershed mismanagement. For example, animal grazing or excessive human use at high elevations can lead to fecal contamination of surface runoff in mountain streams. Urbanization can lead to storm runoff that is lost to sewers rather than feeding streams. Water managers and land-use planners must coordinate whenever these kinds of land-use decisions can lead to irreversible changes in the hydrological cycle.

## 5. Institutions and Management

Criteria for sustainability are not only about measuring appropriate biological or physical indicators. They must also provide guidance for the institutions that are to resolve conflicts over water and deal with the unavoidable uncertainties and risks in decision making. The greatest debates over water in California in the past several decades have focused on how to reach particular *goals.* The water debate must now be broadened to address the *means* by which these goals are set. Accordingly, sustainability criteria must also apply to water-resources management, particularly to ensure democratic representation of all affected parties in decision making, open and equitable access to information on the resources, and the options for allocating those resources.

***The greatest debates over water in California in the past several decades have focused on how to reach particular goals. The water debate must now be broadened to address the means by which these goals are set.***

Water planning and decision-making in California today include a far wider range of individuals and interests than ever before. Nevertheless, such participation is still far from complete, and the power of the three dominant interests, agriculture, urban users, and certain large environmental groups, remains significantly greater than that of smaller rural interests, family farmers, minority groups, and other users. Mechanisms to broaden their participation are needed. Ways must also be found to incorporate and protect the interests of future generations — a fundamental criteria of sustainability as defined by the United Nations in Agenda 21 (UN 1992).

In addition to mechanisms to broaden participation, institutional mechanisms need to be set up to prevent and resolve conflicts over water. A wide range of institutional mechanisms for resolving water disputes already exist in California, though their effectiveness varies greatly depending on the issue and the extent of political manipulation and interference. The institutions of the future must not only be more open and democratic, but must resolve conflicts over water in an equitable, prudent, and fair manner.

Perhaps the greatest flaw with California's existing water institutions is their failure to adequately address issues of equity. Equity is a measure of the fairness of both the distribution of goods and bads as well as the process used to arrive at particular social decisions. The sustainability goals in Table 4 explicitly incorporate institutional criteria for participation and conflict resolution so as to ensure at least a degree of procedural equity that we believe is necessary for sustainability. Some would argue that sustainability should be defined narrowly so that questions of equity are excluded. But from this perspective, sustainability could be achieved under otherwise morally reprehensible conditions. For example, the terrible health conditions in many parts of the world tied to inadequate water supplies are certainly "sustainable", but no ethical argument can be made for sustaining them. Questions of equity overlap with sustainability when trying to determine what is to be sustained, for whom it is to be sustained, and who decides. In general, great disparities in wealth, inequities in power between men and women, and discrimination based on race, ethnicity, or age can lead to conflicts that undermine attempts to achieve sustainability. Thus, a fair political process is itself a necessary component of sustainability.

## D. SUMMARY

The sustainability criteria presented in this report provide a framework for prioritizing competing interests and for making decisions about water use. The first two criteria set out minimum allocations for humans and ecosystems, which are to be satisfied before other demands. In this respect, we follow a similar strategy of defining criteria for "basic needs" laid out by Agenda 21 of the United Nations. As Toman (1992) suggests, "to satisfy the intergenerational social contract, the current generation would rule out in advance actions that could result in natural impacts beyond a certain threshold of cost and irreversibility."

The sustainability criteria not only set out quantity and quality requirements, but they also set an upper limit to water use and provide some institutional guidance. As long as the minimum needs are met, then all remaining demands on water are acceptable as long as they do not impair the renewability of the resource and as long as allocations are equitable between both present and future generations. The criteria do not provide guidance for how to allocate these remaining demands — rather they lay out guidelines for a process of how to decide among conflicting demands. Because these remaining demands often conflict, a higher degree of social value judgments will be required to set standards or even decide which demands should come before another. It is easier to agree and quantify minimum standards for human health, which has some biophysical basis, than it is to determine how much water should be allocated for irrigation or for industrial use, but these decisions need to be made as well. In allocating water to these other demands, guides such as efficiency and equity will be needed.

The sustainability criteria are not meant to be all encompassing. They help answer only certain questions for public policy and planning. A few of the most pressing questions outside the scope of the criteria include:

- How should distinct communities and cultures be protected in the development of water resources?
- What should be the procedure if requirements for humans exceed the requirements for the environment?
- How should the impacts of water resources on the sustainability of other resources such as soil and air be dealt with?

Is California water use sustainable today? If not, why not? The following section discusses current California water use and policies in the context of the sustainability criteria presented above.

# IV. Where Are We: California Water Today

For more than a century, water-resources planning and development in California has been the domain of civil engineers. The prevailing ethic in California has been to plan for future growth by building more dams, reservoirs, and canals to transport water from areas of surplus to areas of deficiency. Not a drop of water was to be wasted by flowing to the sea. As the governor of California, Earl Warren, said in 1945, "put every drop of water to work" (Dunning 1993). With this ethic of supply expansion, water planning became largely a technical exercise. This section traces the history of water planning in California and its breakdown in the last few years, and it details the current state of water use in the urban, agricultural, and environmental sectors.

## A. HISTORY OF THE CALIFORNIA WATER PLAN

In the struggles over California water policy in the last half century, none has been as contentious or momentous as those over the California Water Plan. This Plan has kept California on a particular path of development — one that brought water and prosperity to the agricultural regions of the Central Valley, as well as quenched the thirst of booming southern California cities.

Statewide planning for large-scale water development began much earlier than with the first California Water Plan in 1957. As early as 1874, a federal study proposed large, regional-scale water developments (DWR 1983). The first statewide plan for California water resources was carried out in 1920 by Colonel Robert Marshall, the chief hydrographer of the U.S. Geological Survey (DWR 1983). The first comprehensive "State Water Plan" was commissioned by the 1921 State Legislature and adopted in 1931. Financing for this plan was approved in 1933, but the Great Depression prevented the funds from being raised for construction of the proposed projects. In 1935, the federal government stepped in to construct what became known as the Central Valley Project (Hundley 1992).

Shortly after World War II, the Division of Water Resources began the Statewide Water Resources Investigation to update old plans. The three phases of the investigation were a n inventory of water resources completed in 1951 ("Bulletin 1"), an assessment of the present and "ultimate requirements" for water in California published in 1955 ("Bulletin 2"), and the first "California Water Plan" released in 1957 ("Bulletin 3").[3] The Division of Water Resources became the present-day Department of Water Resources (DWR) in 1956.

Today, the DWR's official mission is "to manage the water resources of California in cooperation with other agencies, to benefit the state's people and protect, restore, and enhance the natural and human environments." Its principal responsibilities are to develop and manage the State Water Project, update the California Water Plan, assist local water agencies, educate the public, and provide flood control and public safety. The Division of Planning is responsible for the periodic updates to the Plan, and its staff "collects and analyzes statewide data on surface and ground water, population, and land and water use; estimates future water needs, surpluses and deficiencies by major hydrologic areas; and identifies potential means of meeting future needs in each hydrologic area" (Ito 1991).

### 1. The Original Plan

The 1957 California Water Plan, also known as Bulletin 3, was a technical exercise in multi-purpose planning.[4] The Plan evaluated supply, estimated current and future water requirements, described existing and potential

[3] As defined in Bulletin 3, the "ultimate" water requirement is that which "pertains to conditions after an unspecified but long period of years in the future when land use and water supply development are at maximum and essentially stabilized." It was recognized that this ultimate requirement depended on future changes in technology.

[4] Multi-purpose planning was developed by water resource engineers to plan for projects which would serve multiple purposes such as irrigation, flood control, and navigation.

water problems, and proposed projects for development. It claimed to be an "ultimate" and "comprehensive" plan, a "flexible framework to be improved," a plan for "ordered development by logical, progressive stages," and a "supplement" to existing development. It did not claim to establish economic feasibility, only technical feasibility. With the completion of the first California Water Plan in 1957, DWR Director Harvey Banks proclaimed that "the full solution of California's water problems thus becomes essentially a financial and engineering problem" (DWR 1957).

*With the completion of the first California Water Plan in 1957, DWR Director Harvey Banks proclaimed that "the full solution of California's water problems thus becomes essentially a financial and engineering problem."*

In the late 1950s, the problem of water in California was viewed as "critical," with water considered the limiting factor in California's future development. There were floods; population growth portended "water deficiencies" in many parts of the state; and groundwater was being overdrafted. The Plan identified areas of "water surplus" and concluded that there would be adequate water for future development as long as the projects proposed by the Plan were built to transport water from areas of surplus to areas of deficiency. When all the available water was harnessed for domestic and agricultural uses or power generation, California would be in an "ultimate" state of development — a steady-state equilibrium.

Since the original Plan was published, the DWR has updated Bulletin 160 six times. Updates were published in 1966, 1970, 1974, 1983, 1987, and 1994. Throughout the reports are common themes of growth in urban and agricultural water use and a reliance on engineering solutions to produce new facilities to accommodate projected demand. While the language of the Bulletins changes over time to reflect the increasing sensitivity to economic concerns and environmental values, the agency's analytical methods have remained essentially the same for 40 years. In 1991, the state legislature amended sections 10004 and 10005 of the Water Code to officially require California Water Plan Updates every five years, the release of a preliminary draft for public comment, and public hearings. Table 6 provides a comparison of the key points in the seven California water plans. For a comparison of the plans' 2020 water demand projections see Figure 3 and Table 6.

## 2. California Water Plan Updates

Bulletin 160-66, the *Implementation of the California Water Plan*, reported on the changes that had occurred since the publication of the original Plan in 1957. The base year for the study was 1960 and projections of water "requirements" were made for 1990 and 2020. Bulletin 160-66 projected very high future water requirements based on the 45 percent increase in population between 1950 and 1960. Extrapolating for the year 2020, California's population was projected to be 54 million.

By the time Bulletin 160-70, *Water for California: The California Water Plan, Outlook in 1970*, was published, future water requirements were revised downward to reflect a slowdown in the rate of population growth. The base year was 1967, with projections again to 1990 and 2020. This report reflected the first sensitivity to environmental concerns, mirroring the dramatic national gains in environmental awareness in the late 1960s. Nevertheless, the projection of continued growth remains key to this report. One of the greatest concerns expressed in this report was that there may be insufficient cooling water to meet the expected demands of the large number of new nuclear power plants projected for the future.

The update for 1974, *The California Water Plan: Outlook in 1974*, departed from the previous Bulletins by analyzing four alternative futures rather than a single projection. These scenarios were based on different assumptions of population growth, per-capita food consumption, foreign trade, per-acre yields of crops, and California's share of national agricultural production. The slowdown in population growth seen in 1966 had continued, and so the projected rate of growth in urban demands for water were again revised downward. Projected agricultural water demand, however, was greater. The underlying message of this Update was that "on a statewide basis, the California water outlook is favorable. There are, however, areas

## Table 6
## Comparison of DWR's California Water Plans, 1957 to 1993

| DWR Bulletin | 3 | 160-66 | 160-70 | 160-74 | 160-83 | 160-87 | 160-93 |
|---|---|---|---|---|---|---|---|
| **Year Published** | 1957 | 1966 | 1970 | 1974 | 1983 | 1987 | 1994 |
| **Title** | The California Water Plan | Implementation of the California Water Plan | Water for California: The California Water Plan:Outlook in 1970 | The California Water Plan: Outlook in 1974 | The California Water Plan: Projected Use and Available Water Supplies to 2010 | California Water: Looking to the Future | California Water Plan Update |
| **Base Year** | 1950 | 1960 | 1967 | 1972 | 1980 | 1980 | 1990 |
| **Final Projected Year** | Ultimate | 2020 | 2020 | 2020 | 2010 | 2010 | 2020 |
| **Demand Categories** | • Irrigation<br>• Urban, suburban, and industrial<br>• Miscellaneous | • Agricultural<br>• Urban<br>• Fish, Wildlife, and Recreation | • Agricultural<br>• Urban<br>• Power Plant Cooling | • Agricultural<br>• Urban<br>• Fish, Wildlife, and Recreation | • Agricultural<br>• Urban<br>• Wildlife and Recreation<br>• Energy Production | • Agricultural<br>• Urban<br>• Environmental<br>• Energy Production | • Agricultural<br>• Urban<br>• Environmental<br>• Other (includes conveyance losses, recreation uses, and energy production) |
| **Scenarios** | Single scenario of ultimate requirements | Single demand and supply scenario | Single demand and supply scenario | Four demand scenarios and a single supply | Single demand and supply | Single demand and supply scenario | Single demand scenario and two supply scenarios (average and dry year) |
| **Population in Final Projected Year (million people)** | n/a | 54.30 | 44.70 | 36.60 | 34.38 | 36.28 | 48.90 |
| **Irrigated Acreage in Final Projected Year (million acres)** | 19.98 | 10.78 | 10.24 | 9.85 | 10.95 | 9.50 | 9.32 |
| **Term for Water Demand** | Requirement | Requirement | Demand | Demand | Use | Use | Demand |
| **Key Problems and Current Situation** | • Floods in 1955.<br>• Water "deficiency" in certain areas.<br>• Groundwater overdraft in certain areas. | • Continued growth in population, industry, and irrigated agriculture.<br>• Flood problems increasing and may need flood control dams.<br>• Groundwater overdraft and water quality problems in some agricultural areas. | • Sufficient developed water, but conveyance facilities needed.<br>• Resistance to and litigation over new construction projects.<br>• Continuing growth in population and irrigated acreage.<br>• New demands for cooling water. | • New stringent water quality goals and Wild and Scenic Rivers program.<br>• Groundwater overdraft will worsen in San Joaquin Valley until surplus Sacramento water delivered.<br>• Drought years could cause difficulty.<br>• Increasing salinity in some ground water basins and continuing overdraft in San Joaquin Valley. | • Water supply sufficient for 1980, but delays in constructing projects could cause future difficulties.<br>• Continued population growth will require looking at all forms of water management.<br>• Overdraft continues.<br>• Leveling off of irrigation water use. | • Water supply is sufficient in 3 out of every 4 years.<br>• In dry years, reservoirs and groundwater are drawn upon, and conservation and perhaps rationing are required. | • Six year drought from 1987 to 1992.<br>• CVPIA (1992) and other actions taken to protect environment.<br>• During drought, present supplies insufficient to meet demands.<br>• Without more facilities and improved management, there will be severe shortages by 2020. |

facing distress and some uncertainties in the future that will require corrective action." Some of the projected problems include salinization of groundwater and continuing groundwater overdraft. The Bulletin also discussed how the environmental movement's values "are highly qualitative, judgment oriented, and not readily adaptable to quantitative expression or economic dimensioning." The DWR's response was to "adopt a reasonable balance between economic factors and subjective factors to provide opportunity for the economically handicapped portion of society to increase its level of economic affluence to a point where it can participate in the natural environment and esthetic amenities of California." In other words, the major environmental concern expressed was how to make the poor rich enough to participate in the recreational opportunities afforded by California's environment.

The fourth Bulletin 160, *The California Water Plan: Projected Use and Available Water Supplies to 2010*, was not published until 1983. It defines itself as "essentially a technical report" and a "user's manual." The base year is 1980 with projections at ten-year intervals out to 2010. The population projection is revised upwards a bit from the 1974 estimate but is still lower than the 1970 projection. Although a slowdown in irrigated acreage relative to historical trends is admitted, irrigated acreage projections are revised upward from both the 1970 forecast and 1974's "most reasonable future" scenario. The basic outlook in this report is that while water supplies were sufficient in 1980, delays in constructing projects "could cause widespread difficulties in the future," such as increased groundwater overdraft in the San Joaquin Valley. No specific recommendations were made in the report.

The fifth Bulletin 160 appeared in 1987 as *California Water: Looking into the Future*. This Update is more polished than the others, but takes a broader, qualitative view of water events and issues in California. Overall, there are fewer numbers and supporting data reported. The years for which demands are estimated are 1980, 1985, and 2010. While every Update except the first had used the term "water demand," this one uses the term "water use." Similar to Bulletin 160-83, options for future water supply are discussed, but no specific recommendations are made.

## 3. The California Water Plan in the 1990s

The 1983 and 1987 updates to the California Water Plan were ill received and largely seen as irrelevant to water policy. By the late 1980s and early 1990s, values among California residents had changed from supporting new physical development to preservation of instream values, and political pressure had halted the era of big dams. Despite this change, planners continued to operate the same models to predict demand growth and talked of the need to build more dams and aqueducts to prevent a coming disaster. State water planners have been planning for a future that now appears increasingly unlikely and undesirable.

***State water planners have been planning for a future that now appears increasingly unlikely and undesirable.***

The latest update, released in November 1994, represents perhaps a turning point in California water planning.[5] Although it is more a reference document than a "plan," the DWR did assemble a public advisory committee to act as a sounding board for the planning process and the report's structure. To its credit, the DWR brought to the process some new voices that reflect a broader spectrum of interests. As a result, the Update is easier to read and includes more information than any of the previous Bulletin 160s. Bulletin 160-93 includes some limited economic analysis, a drought-year scenario, and a discussion of demand-management options. Under this latest version, water supply must be "reliable" for growing populations, agriculture, and industrial development. Growth in demand will continue and can be partly met by "stretching" supply through demand-side measures as well as by building some new water-supply projects.

[5] See Loh 1994 for an in-depth analysis of the DWR's most recent statewide planning process.

Despite this consideration of demand management, the basic approach taken by the DWR in the latest Plan Update remains largely the same as in the past, and the projected "gap" between demand and supply in the year 2020 remains large. Projections of future demand are still made without supply constraints, and unsustainable practices, such as groundwater overdraft, are implicitly assumed to continue. There is very little vision of where the state should be heading and how we might get there.

## B. URBAN WATER USE TODAY

More than ninety percent of California's population lives in an urban setting, with over 80 percent living in metropolitan areas of one million people or more (Bank of America 1995). This growing population is increasingly competing for water traditionally used elsewhere. To meet urban needs in the past, dams, aqueducts, and pipelines were built to bring water used by natural ecosystems and rural communities to the cities. This supply-oriented growth philosophy is now changing. For economic, environmental, and social reasons, urban water planners have begun to re-evaluate their mission and to look for new tools in their search for reliable, safe water supplies. Even with California's extensive statewide water infrastructure, our cities can no longer look outward for water, but must instead begin looking inward.

Beginning in 1987, California entered one of the most severe droughts in recorded history. For six years, average runoff dropped almost in half, the state's largest reservoirs were drained nearly dry, and water users found themselves facing a bleak future. The drought produced criticism and re-evaluation of nearly all forms of water use, from agricultural practices to environmental water uses. The drought also prompted planners to reassess the management of urban water resources, focusing on policies to improve urban water-use efficiency. If the use of water in metropolitan areas continues to rise in the future, as anticipated, mismanagement and inefficient use will become less and less tolerable. On the positive side, many changes can easily be made to improve the efficiency of water use in homes, businesses, and industries, and these changes can have positive effects on lifestyle, the economy, and California's water situation.

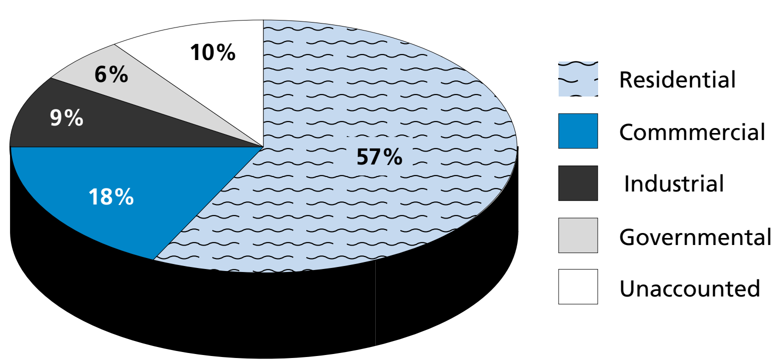
***Even with California's extensive water infrastructure, our cities can no longer look outward for water, but must instead begin looking inward.***

*Major artificial reservoirs, such as Clair Engle, are heavily drawn down during droughts. (Courtesy of DWR.)*

Urban water requirements include the water used for all residential, commercial, industrial, and governmental needs. According to the DWR, applied urban water used for 1990 totaled 7.8 million acre-feet (maf), about one-fourth the water used by the agricultural sector and only 11 percent of the total statewide applied water use.[6] The biggest urban user, as reported by the DWR and as illustrated in Figure 4, is the resi-

**Figure 4**

**1990 Applied Urban Water Use, by Sector**




*Source: DWR 1994a.*

[6] All figures drawn from the DWR's 1990 estimates are "normalized" by DWR, not "actual." They represent what demand could have been had it been an average water supply year rather than a drought year. Thus, actual figures for 1990 are lower than DWR's because of conservation efforts and cutbacks to agricultural users.

**Table 7**
**1990 Residential Water Use, by Hydrologic Region**

| Region | Population (millions) | Total Residential Applied Water Use[a] (thousand acre-feet) | Residential Per-Capita Applied Water Use (gallons per person per day) | Residential Applied Water Use (as a percent of total urban) |
|---|---|---|---|---|
| North Coast | 0.6 | 92 | 137 | 52 |
| San Francisco | 5.5 | 650 | 106 | 54 |
| Central Coast | 1.3 | 160 | 112 | 60 |
| South Coast | 16.3 | 2,260 | 124 | 59 |
| Sacramento River | 2.2 | 420 | 169 | 56 |
| San Joaquin River | 1.4 | 340 | 216 | 70 |
| Tulare Lake | 1.5 | 340 | 202 | 67 |
| North Lahontan | 0.1 | 18 | 160 | 38 |
| South Lahontan | 0.6 | 120 | 175 | 63 |
| Colorado River | 0.5 | 190 | 336 | 59 |
| California Weighted Average[b] | | | 137 | 59 |
| **Total California Applied Residential Water Use** | **30.0** | **4,590** | | |

[a] *The column total residential applied water use is the product of the regions' per-capita water use multiplied by the regions' 1990 population.*

[b] *The residential per-capita weighted average was calculated by dividing the total California applied residential water use by the 1990 state's population, and converting to gallons per person per day. DWR (1994a) variously estimates residential applied water use to be between 57 and 59 percent of total urban water use.*

*Source: DWR 1994a.*

dential sector (57 percent), followed by the commercial (18 percent), industrial (9 percent), and governmental (6 percent) sectors (DWR 1994a). DWR water use data show that total urban water use has been increasing steadily. In 1972, urban water use was estimated to be 5.0 maf, rising to 5.8 maf by 1980, and then to an estimated 7.8 maf by 1990. Urban water use is projected in the latest DWR 160 series water plan to rise by an additional 60 percent by the year 2020 to 12.7 maf, mostly due to increasing population (DWR 1994a).

### 1. Residential Sector

According to DWR data, California residents used about 4.6 maf in 1990, up from 3.5 maf in 1980. Estimates are that the residential sector used between 57 and 59 percent of the total urban water demand in 1990.[7] Statewide, residential per-capita water use is approximately 137 gallons per day, but varies tremendously from region to region. The range spans a low of 106 gallons per person per day in the San Francisco region to a high of 336 gallons per person per day in the Colorado River region, as illustrated in Table 7. By the year 2020, based on the DWR's water-use projections and population estimates, total residential water use will have increased from 4.6 maf to 7.5 maf.

Residential water use includes both indoor and outdoor demands and is influenced by numerous factors, including climate, type and density of housing, income level, and kinds of water-using appliances. Family size, metering, and water costs also influence household and per-capita water use. Climate and weather conditions have substantial impacts on outdoor water use, most of which is for lawn and garden irrigation. As temperatures increase, water

[7] Actual residential water use estimates in DWR's Bulletin 160-93 vary from 4.4 to 4.6 million acre-feet, reflecting an inadequate data base. We estimate residential water use to be closer to 4.6 million acre-feet when more detailed regional data are used. This is 59 percent of total urban water use—slightly higher than DWR's estimate of 57% (DWR 1994a, page 153) or 58% (DWR 1994a, page 154).

*Maintaining lawns in semi-arid environments can be water-intensive, especially if watering is done improperly. (Courtesy of DWR.)*

use rises. Conversely, the greater the rainfall, the lower the water use.[8] Higher-density developments and multi-family units generally use less water per resident than do single-family houses. In large part, this is due to outdoor water uses. Apartments and other multi-family dwellings such as condominiums normally use less water, on a per-capita basis, but their water use also varies greatly depending on climate, lot size, the extent of landscaping, and other variables. In 1985, the estimated average residential water use in southern California for a single-family unit was 384 gallons per day, or 128 gallons more than a multi-family unit (Dziegielewski et al. 1991).

*Many urban water uses can be wasteful when water is scarce. (Courtesy of DWR.)*

Table 3 shows a breakdown of 1990 California residential indoor and outdoor average per-capita water use. These end-use estimates are based on DWR's 1990 distribution of indoor and outdoor water use and can be used to forecast potential savings from different technologies and practices.

Individuals with higher income generally use more water on a per-capita basis than those with lower income. Increases in income often result in the purchase of additional water-using appliances and additional landscaping, which cause residential water use to rise. For example, some studies have shown that in single-family households, a 10 percent increase in income is associated with a three to six percent increase in water use (DWR 1994b). Higher-income communities also often choose to support water-using activities such as municipal irrigation in lawns and golf courses. These kinds of data can help identify where water savings might be found and the role of economic factors in generating those savings.

### 2. Industrial Sector

Producing the goods we use in our everyday life — from clothes and computers to food products, paper, plastics, and televisions — requires large amounts of water. Producing one ton of paper with commonly used practices can consume as much as 700 tons of water. Making a ton of steel can take 280 tons of water (Postel 1992). Brewing a gallon of beer may take as much as 170 gallons of water for processing, cooling, and other uses (U.S. Water News 1994a).

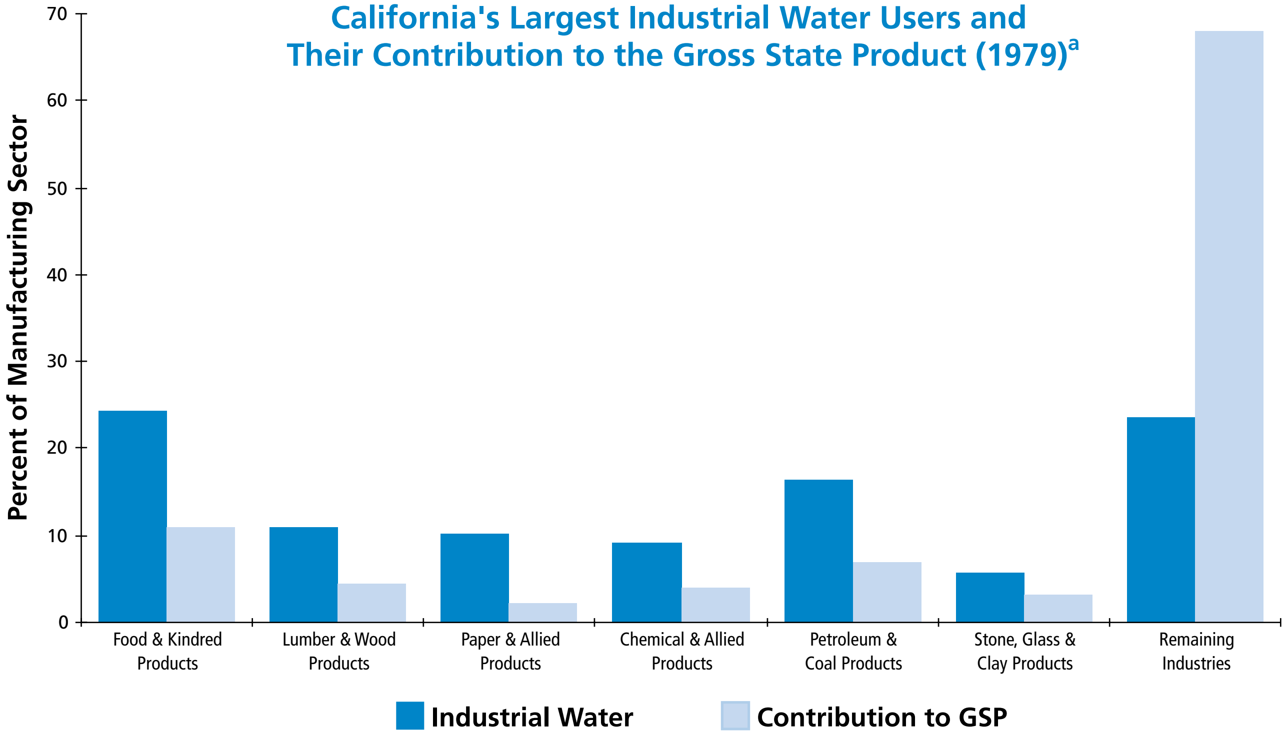
Comprehensive data on industrial water use in California are often not available or are contradictory. No overall survey of industrial water use in the state has been completed since 1982, and the data in that report are from the late 1970s (DWR 1982). In 1979, the industrial sector used about 920,000 acre-feet of water — 14 percent of total urban water use. The six largest water-using industries, in order of total water use, were food and kindred products, petroleum and coal products, lumber and wood products, paper and allied products, chemical and allied products, and stone, glass, and clay products. These six industries used 76 percent of all industrial water, but produced only 30 percent of total industrial revenue. (See Figures 5 and 6.)

By 1990, the DWR estimated that water use in the industrial sector had dropped to about 620,000 acre-feet (or 9 percent of total urban water use) — representing an absolute decline

[8] A study of southern California water agencies found that 28 percent of total residential water use was seasonal (i.e., those uses that vary from month to month in response to weather conditions) (Dziegielewski et al.1990, 1991).

**Figure 5**

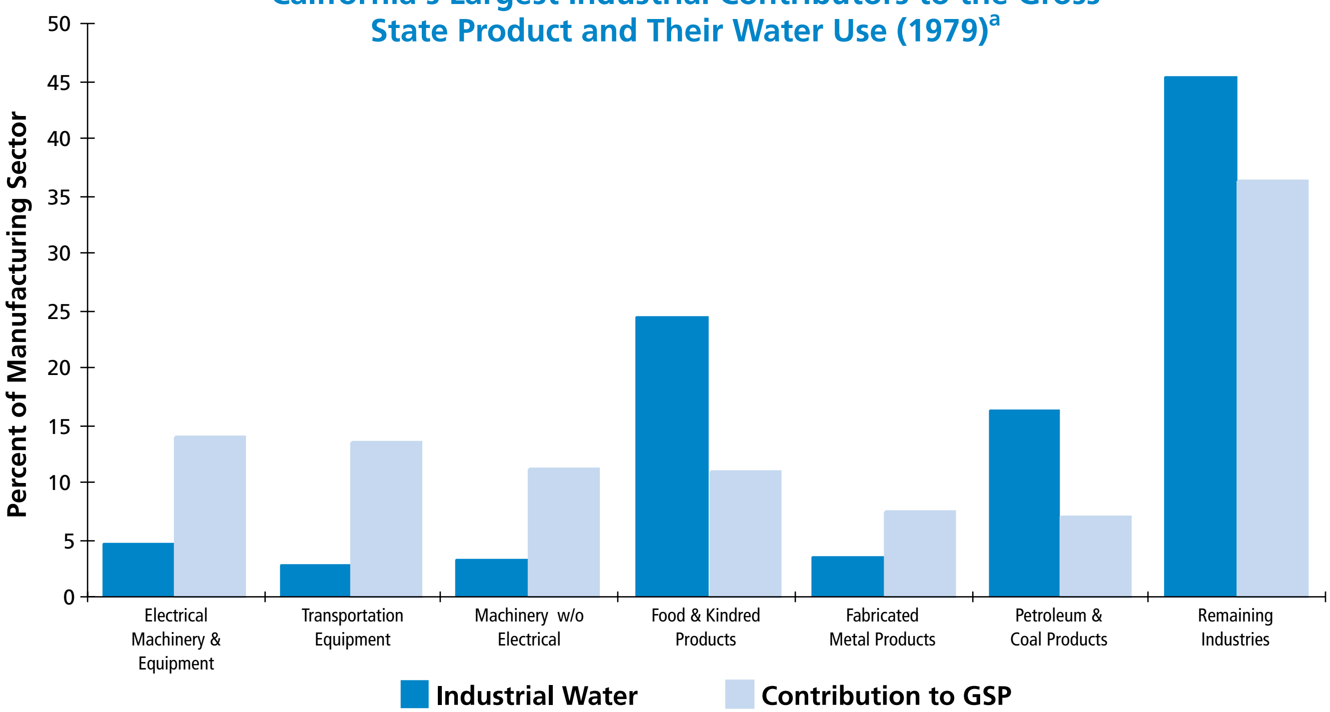
**California's Largest Industrial Water Users and Their Contribution to the Gross State Product (1979)[a]**




[a] *The manufacturing sector represented approximately 19 percent of 1979 Gross State Product.* *Source: DWR 1982.*

**Figure 6**

**California's Largest Industrial Contributors to the Gross State Product and Their Water Use (1979)[a]**




[a] *The manufacturing sector represented approximately 19 percent of 1979 Gross State Product.* *Source: DWR 1982.*

of 300,000 af from 1979 (DWR 1994a, 1994b). During the same period, total gross industrial production rose 30 percent in real terms (DOF 1994). In 1979, on an industry-wide level, it took an average of 11 acre-feet of water to produce a million dollars of industrial output. By 1990, this figure had dropped to under six acre-feet. While details explaining how this improvement in industrial water-use efficiency occurred are sketchy, two important trends are evident: (1) an improvement in the efficiency with which water is used by many of the industrial sectors, and (2) a shift in the industrial structure of the state away from water-intensive industries. These changes were partly driven by new water-quality standards, the cost of water, the cost of treating wastewater, and technological improvements.

Between 1985 and 1990 seven major industrial groups (fruits and vegetables, beverages, paperboard and boxes, refining, concrete, communications, and motor vehicles) showed positive annual growth rates and absolute declines in annual water use. Six of these groups improved water-use efficiency more than 40 percent (see Table 8). Five other major industries increased their economic output at rates substantially higher than the rates at which water use increased (meat, bakery, and foods, metal cans, computers, computer components, and missiles/space).

### 3. Commercial and Governmental Sectors

Water use in the commercial sector grew from 14 percent of total urban water use in 1980 to 17 percent in 1990. Although water use figures in the commercial sector are supposed to exclude governmental water uses, classification methods used by some water agencies combine commercial and governmental categories. Thus, a standardized SIC grouping to describe water use in this sector would be extremely useful. Table 9 provides a breakdown of 1990 commercial applied water use by hydrologic region.

Because of population concentrations, two of the state's ten hydrologic regions — the South Coast and San Francisco — account for over 70 percent of the total commercial water use in California, and adding the Sacramento River region raises the percentage to more than 80 percent. On a per-capita basis, commercial water use in California's hydrologic regions is relatively uniform, with the exception of the Colorado River area with an unusually high commercial per-capita water use of 127 gallons per day, most likely due to substantial outdoor water use.

Water use in the governmental sector now stands at about 6 percent of total urban use.

**Table 8**
**Improvements in Industrial Water-Use Efficiency: 1985 to 1989**

| Standard Industrial Classification Code | Industry Group | 1989 Water use index (1985 = 100) |
|---|---|---|
| 285 | Paint | 46 |
| 357 | Computers | 50 |
| 371 | Vehicles | 57 |
| 367 | Electronic Components | 56 |
| 203 | Fruits and Vegetables | 61 |
| 372 | Aircraft | 63 |

*Source: Wade et al. 1991.*

Although DWR has recently made an effort to clarify and standardize all urban classifications, it acknowledges that the commercial and governmental water use estimates frequently overlap (DWR 1994b).

### 4. Reclaimed Water Use

The vast majority of urban water use ends up down the drain. This water goes either to wastewater treatment plants or ends up in local septic systems, where it sits before percolating to groundwater. In recent years, there has been an increased interest in capturing and treating wastewater. Drought conditions limiting supply, environmental problems with sewage disposal, and growing demands, have all made water reclamation more appealing in urban areas.

Reclaimed water can be used to recharge groundwater aquifers, supply certain industrial processes, irrigate certain edible or ornamental crops, or fulfill other purposes. At present,

**Table 9**
**1990 Commercial Applied Water Use, by Hydrologic Region**

| Region | Population (millions) | Total Commercial Applied Water Use[a] (thousand acre-feet) | Commercial Per-capita Applied Water Use[b] (gallons per person per day) | Commercial Applied Water Use (as a percent of total urban) |
|---|---|---|---|---|
| North Coast | 0.6 | 27 | 39 | 15 |
| San Francisco | 5.5 | 260 | 42 | 22 |
| Central Coast | 1.3 | 44 | 30 | 16 |
| South Coast | 16.3 | 690 | 38 | 18 |
| Sacramento River | 2.2 | 130 | 51 | 17 |
| San Joaquin River | 1.4 | 39 | 25 | 8 |
| Tulare Lake | 1.5 | 51 | 30 | 10 |
| North Lahontan | 0.1 | 9 | 80 | 19 |
| South Lahontan | 0.6 | 24 | 36 | 13 |
| Colorado River | 0.5 | 71 | 127 | 22 |
| California Weighted Average | | | 40 | 17 |
| **Total California Applied Commercial Water Use** | **30.0** | **1,345** | | |

[a] *The total commercial applied water use column is the product of the regions' per-capita water use and the regions' 1990 population.*

[b] *The commercial per-capita applied water use column was calculated by multiplying DWR's 1990 total urban applied water use by the commercial percentage. DWR (1994a) variously estimates commercial water use between 17 and 18 percent of total urban water use.*

*Source: DWR 1994a.*

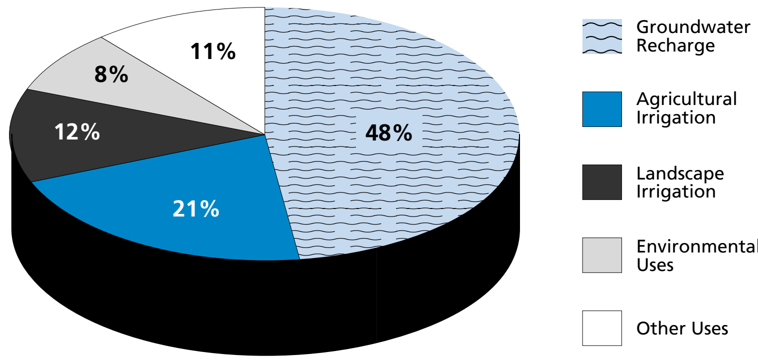
*Decorative uses of potable water in commercial or municipal settings can also be wasteful, because of evaporative losses. (Courtesy of DWR.)*

according to a 1993 WateReuse Association of California report, 48 percent of the reclaimed water being used goes to recharge groundwater aquifers. Twenty-one percent of the reclaimed water is used for agricultural irrigation and 12 percent for landscape irrigation. The environmental sector, despite being a prime candidate for reclaimed water use, uses only eight percent, with the remaining 11 percent of the reclaimed water meeting a variety of other needs (WateReuse Association of California 1993)(see Figure 7).

A paucity of reliable, current data makes an accurate determination of the total amount of water currently being reused in California difficult. For example, reports from the Department of Water Resources (DWR 1994a, 1994b) estimate statewide reuse at 384,000 acre-feet per year, citing the 1993 WateReuse Association report mentioned above (WateReuse Association of California 1993). No updated statewide estimates for water recycling have since been released. Moreover, these numbers come from a study that acknowledged poor survey response in certain regions, particularly the Central Valley.

Adding newer data from those regions, we conclude here that by the end of 1995, water reuse in California is likely to be between 526,000 and 665,000 acre-feet per year. At the same time, however, we estimate that more than 2 million acre-feet of potentially usable water is still being discharged into the oceans every year after being treated.

**Figure 7**
**1990 Uses of Reclaimed Water**




*These data come from WaterReuse (1993). Several other statewide studies have been released in the last five years, finding substantially different proportions of water reuse. For example, a State Water Resources Control Board study released in 1990 reported that in 1987 agricultural water use accounted for 63 percent of total reclaimed water in the state followed by groundwater recharge with 14 percent. Another survey titled Water Recycling 2000, which was released in late 1991, found that agriculture used 53 percent of all reclaimed water while groundwater recharge accounted for 21 percent. The discrepancy in results between the studies can be attributed to a number of factors, including poor response rates in certain regions and varying definitions of water reuse.*

## 5. Urban Groundwater Use

In 1990, groundwater supplied about seven percent of net urban water demands in California (Solley et al. 1993). Although most of the state's groundwater overdraft occurs in agricultural areas, some urban areas still pump groundwater at a rate faster than it is replenished (DWR 1994a). Overdraft can lead to seawater intrusion into the aquifer, degradation of water quality, and the permanent reduction of groundwater storage capacity through land subsidence.

Urban overdraft can occur because of poorly defined water rights, a lack of coordination among groundwater users, and uncertainty regarding the physical characteristics of the aquifer. For example, in the case of the West Basin of Los Angeles County (which covers the coastal area from Inglewood to the Palos Verdes Peninsula), more than 500 parties were overpumping groundwater by the early 1940s. Wells along the coast were becoming increasingly saline. Several other basins in the Los Angeles area faced similar situations. In these cases, local negotiations and litigation eventually lead to solutions to groundwater overdraft. Key steps included the gathering and public release of information about pumping rates and safe yields, the formation of basin associations, and the clear adjudication of water rights (Ostrom 1990).

Currently, there are several forms of groundwater management in the state. Thirteen basins, including the West Basin, are regulated by court-appointed water masters. With one exception, all of these basins are located in southern California. Nine agencies or groundwater management districts have been established. Three other districts manage groundwater through charges on pumping. These examples of successful local groundwater management show that overdraft problems can be eliminated.

## C. AGRICULTURAL WATER USE TODAY

Any vision of future water use in California must consider the future of both agriculture and the closely related communities and industries that depend on agriculture. California agriculture plays a special role in the nation's food production. With less than three percent of the nation's farmland, California's highly productive central and coastal valleys produce more than 11 percent of total U.S. agricultural revenue. California grows more than 200 crops, and produces more than 90 percent of the following crops grown in the U.S.: artichokes, processed tomatoes, almonds, apricots, dates, figs, grapes, kiwifruit, nectarines, olives, pistachios, and walnuts (DOF 1993). In 1990, even under drought conditions, half of all U.S. vegetables and fruits were produced in California (DOF 1993). This bountiful harvest is highly dependent on the supply of irrigated water. Thirty percent of California's 30 million acres of farmland, and nearly all of the harvested cropland, are irrigated — three times the U.S. average.

Agriculture deserves special analysis here not simply because of its historical role, but because of its integral connection to California water resources. Agriculture accounts for over three-quarters of the net societal water demand in the state (DWR 1993). As an industry, agricultural revenues in 1990 were $18.6 billion, which accounted for 11.1 percent of total U.S. farm income and less than four percent of California's GDP (DOF 1993). According to one study, agricultural and related industries account for about nine percent of Gross State Product (GSP) and 10 percent of the total jobs in the state in 1989. In the Central Valley, the impact of agriculture and related industries is much higher, accounting for 27 percent of the region's gross product and 29 percent of jobs (Carter and Goldman 1992).

Agriculture is not as mobile as other industries. Soil and climatic conditions in California allow for a level of agricultural productivity difficult to achieve elsewhere. More importantly, agriculture is vitally tied to the well-being of many rural communities in the state. Communities that have been created around the agricultural industry have a set of unique problems. Even though the industry as a whole generates large amounts of revenue and profit, there are extreme disparities in wealth, measured in different ways. There are "pockets of poverty" scattered throughout agricultural regions. For example, unemployment in the Central Valley in 1989 was about eight percent while for California as a whole it was only five percent (Kroll et al. 1991). In towns such as Mendota on the west side of the San Joaquin Valley, a quarter of all households are on welfare as compared to nine percent for the state as a whole (Bancroft 1993).

Agriculture in California is more commercial and corporate than the rest of the country. Of California's 82,000 farms, 2,816 farms (or 3.4 percent of all farms) each produce at least $1 million in annual revenues, accounting for over 2/3 of total production. Farms with less than $100,000 annual revenues (66,000 farms) comprised only 1/20 of all production (Villarejo and Runsten 1993).

Hired labor outnumbers family farmers four-to-one (Carter and Goldman 1992). Due to the seasonal nature of agricultural work, more than 90 percent of farm workers piece together numerous different jobs over the course of a year; less than 10 percent of seasonal farm labor is performed by those who are only in the labor market for part of the year (Villarejo and Runsten 1993). About 40 percent of agricultural laborers migrate during part of the season (Villarejo and Runsten 1993). Over 90 percent of farm workers are foreign born, the majority being from Mexico and Latin America. Increasing numbers of workers are indigenous peoples arriving from the southern Mexican state of Oaxaca and other Central American countries.

### 1. Crop Production

Considerable detail on California's agricultural sector is available in a wide variety of publications (e.g., DOF 1993, CASS 1993, and DWR 1994a). In 1990, over 9.5 million acres of crops were irrigated and some of these acres were double- or even triple-cropped each year (normalized data, DWR 1994a). Tables 10 and 11 provide data on irrigated crop acreage and production for major crop types for 1960, 1980, and 1990.

**Table 10**
**Irrigated Acreage of Selected Crops for 1960, 1980, and 1990, Sorted by Crop Acreage**

| 1960 Irrigated Crop | 1960 Thousand Acres | 1980 Irrigated Crop | 1980 Thousand Acres | 1990 Irrigated Crop | 1990 Thousand Acres |
|---|---|---|---|---|---|
| Pasture | 1,521 | Cotton | 1,545 | Other Truck[a] | 1,376 |
| Alfalfa | 1,230 | Grain | 1,485 | Cotton | 1,244 |
| Grain | 1,067 | Other Field[b] | 1,108 | Alfalfa | 1,134 |
| Other Truck[a] | 920 | Pasture | 1,041 | Other Deciduous[c] | 1,080 |
| Other Field[b] | 817 | Alfalfa | 986 | Grain | 988 |
| Cotton | 812 | Other Truck[a] | 969 | Pasture | 955 |
| Other Deciduous[c] | 687 | Other Deciduous[c] | 943 | Other Field[b] | 894 |
| Vineyard | 447 | Vineyard | 683 | Vineyard | 748 |
| Rice | 374 | Rice | 545 | Rice | 517 |
| Subtropical | 330 | Subtropical | 409 | Subtropical | 419 |
| Sugar Beets | 170 | Sugar Beets | 210 | Sugar Beets | 216 |
| **California Total** | **8,374** | **California Total** | **9,924** | **California Total** | **9,571** |

[a] *Includes tomatoes.*
[b] *Includes corn.*
[c] *Includes almond/pistachios.*
*Sources: DWR 1966, 1983, 1994a.*

**Table 11**
**Total Irrigated Crop Acreage, 1960, 1980, and 1990**

| Irrigated Crop | Thousand Acres 1960 | Thousand Acres 1980 | Thousand Acres 1990 | Percent Change 1960 to 1990 | Percent Change 1980 to 1990 |
|---|---|---|---|---|---|
| Grain | 1,067 | 1,485 | 988 | -7.4 | -33.5 |
| Rice | 374 | 545 | 517 | 38.1 | -5.1 |
| Cotton | 812 | 1,545 | 1,244 | 53.2 | -19.5 |
| Sugar Beets | 170 | 210 | 216 | 27.3 | 2.9 |
| Corn | with other field | 442 | 403 | N/A | -8.8 |
| Other Field | 817 | 666 | 491 | 9.4[a] | -26.3 |
| Alfalfa | 1,230 | 986 | 1,134 | -7.8 | 15.0 |
| Pasture | 1,521 | 1,041 | 955 | -37.2 | -8.3 |
| Tomatoes | with other truck | 221 | 352 | N/A | 59.3 |
| Other Truck | 920 | 748 | 1,024 | 49.5[b] | 36.9 |
| Almonds/Pistachios | with other deciduous | 407 | 510 | N/A | 25.3 |
| Other Deciduous | 687 | 536 | 570 | 57.3[c] | 6.3 |
| Subtropical | 330 | 409 | 419 | 27.0 | 2.4 |
| Vineyard | 447 | 683 | 748 | 67.5 | 9.5 |
| **California Total** | **8,374** | **9,924** | **9,571** | **14.3** | **-3.6** |

[a] *Includes corn for 1990.*
[b] *Includes tomatoes for 1990.*
[c] *Includes almonds and pistachios for 1990.*
*Sources: DWR 1966, 1983, 1993.*

The most dramatic trend shown by these tables is the increase in production of fruits and vegetables over the last two decades. During this period, vegetable output increased almost 100 percent, and tree fruit volume increased over 40 percent (Villarejo and Runsten 1993). This shift into more labor-intensive and high value crops has been accompanied at the same time by a shift away from field crops. The move towards fruits and vegetables has been driven in part by increasing American demand as well as expanding markets abroad for fresh fruits and vegetables. In 1989, U.S. per-capita consumption of fresh vegetables was 101 pounds per year compared with only 72 pounds per year twenty years earlier (Villarejo and Runsten 1993). About half of the growth in fruits and vegetables is accounted for by expansion of acreage while the other half is due to an increase in crop yields (Villarejo and Runsten 1993).

*Major irrigation pumps taking water from the Sacramento River. (Photo: P. Gleick)*

*Sprinkler irrigation in Hesperia, California. (Courtesy DWR.)*

*Flood irrigation is an inefficient way to bring water to crops because of the high evaporative losses. (Courtesy of DWR.)*

The livestock industry shows a similar shift in the last twenty years away from grazing towards more intensive production of dairy products, poultry, and eggs. The fastest growing part of California agriculture is the nursery and greenhouse crop sector. Ornamental horticulture produces the highest value output per acre of all agricultural crops. In San Diego County nursery and flower products — capable of paying relatively high prices for water — are the leading agricultural commodity. As some areas of the state rapidly urbanize and replace farmland, the growth in demand for horticultural products has increased.

## 2. Agricultural Water Use

Irrigated agriculture in California applies nearly 30 million acre-feet of water per year, from both surface and groundwater supplies (DWR 1994a). Furrow and flood irrigation are used on half of this land; sprinklers on 35 percent, and highly efficient drip and microsprinkler techniques on about 10 to 15 percent of the land (Sunding et al. 1994).

Water requirements for different crops vary tremendously, depending on crop type, soil and climatic conditions, and irrigation methods. Some crops are very water intensive; others require much less water. Figures 8 and 9 provide selected revenue and water use estimates by selected crop type. As these figures illustrate, certain crops are very water-intensive from an economic point of view.

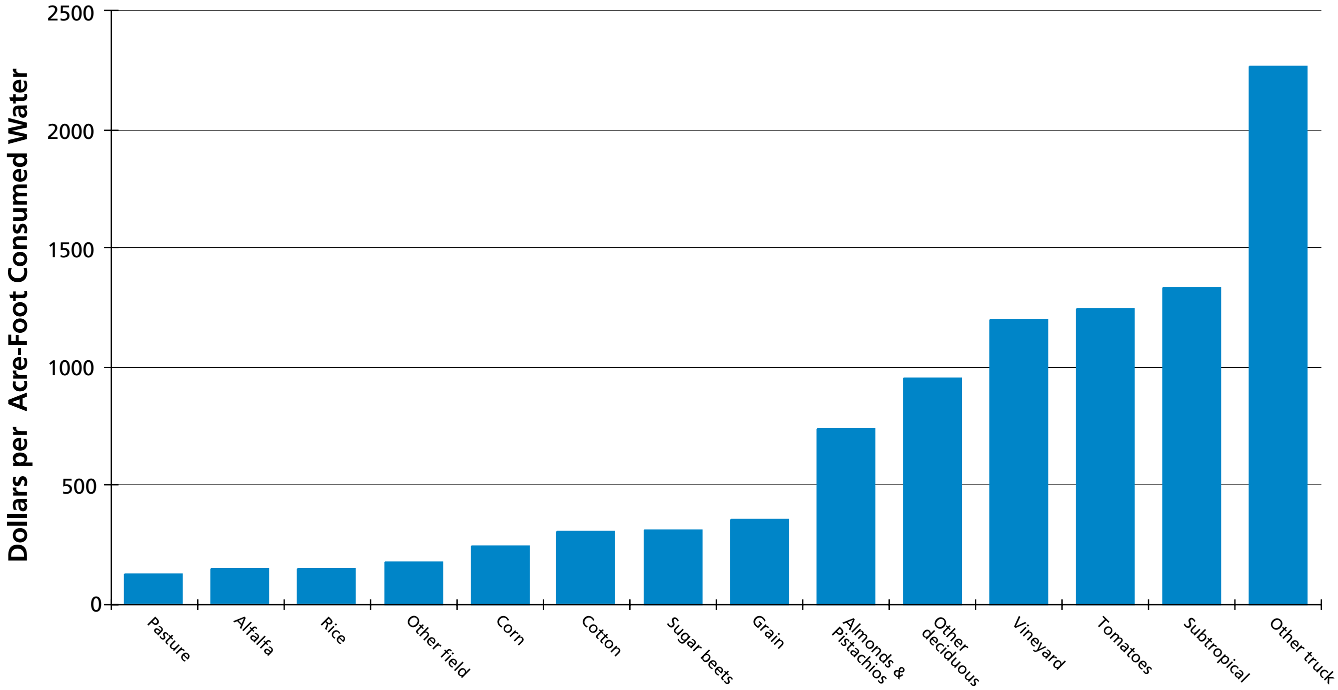
These disparities lead to enormous differences in water productivity. (Sunding et al. 1994) have estimated that the least productive 20 percent of irrigation water in terms of farm value produced less than five percent of total agricultural revenues. Most of this water goes to produce alfalfa hay and rice with flood irrigation. Conversely, the top 20 percent of water produces nearly 60 percent of total farm revenue. (See Figure 10.) These data alone suggest that crop substitution and changing patterns of irrigation can produce substantial water savings. Under certain conditions, net farm revenues could be expected to rise significantly while total water use drops. These scenarios are explored in more detail later.

## 3. Groundwater Use in Agriculture

Groundwater use is extremely important for California agriculture. Substantial volumes of water are pumped from aquifers during the growing season to either supplement surface deliveries of water, or to provide irrigation water when limited or no surface supplies are

**Figure 8**

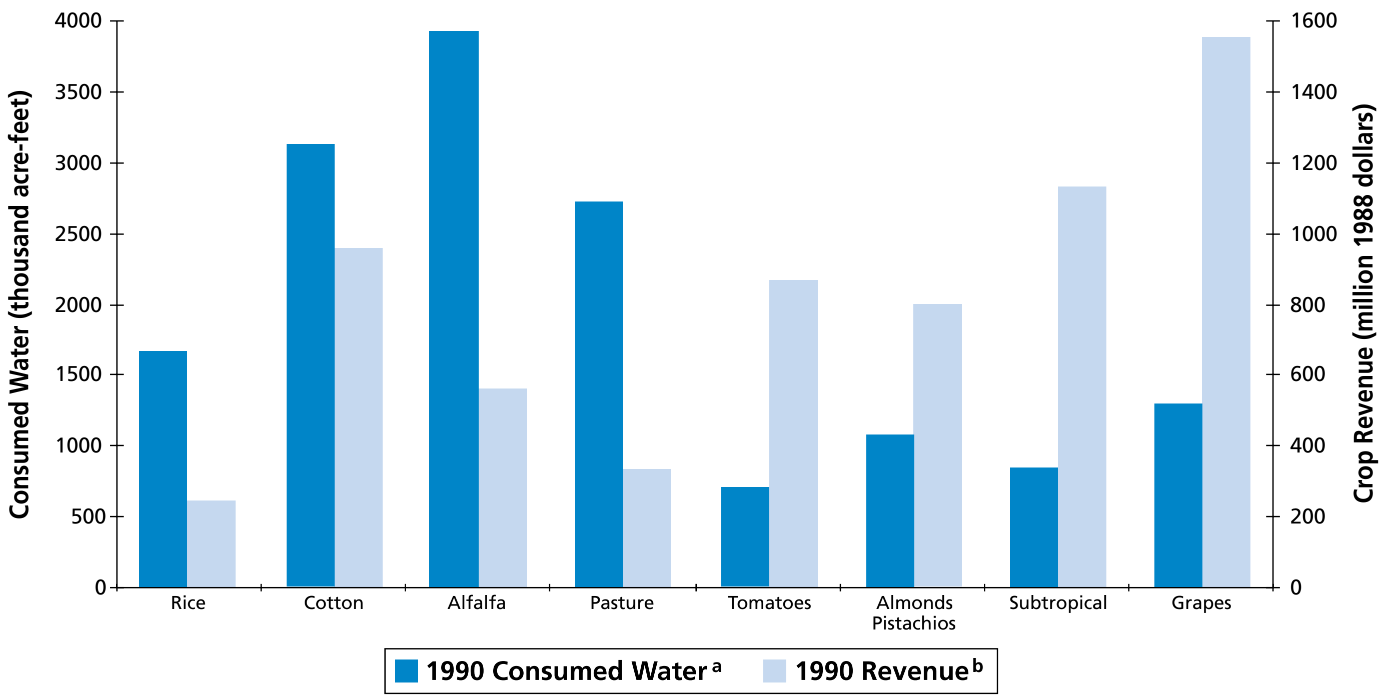
**Revenue Per Acre-Foot of Consumed Irrigation Water (1988)**




*Sources: DWR 1994a and Zilberman et al.*

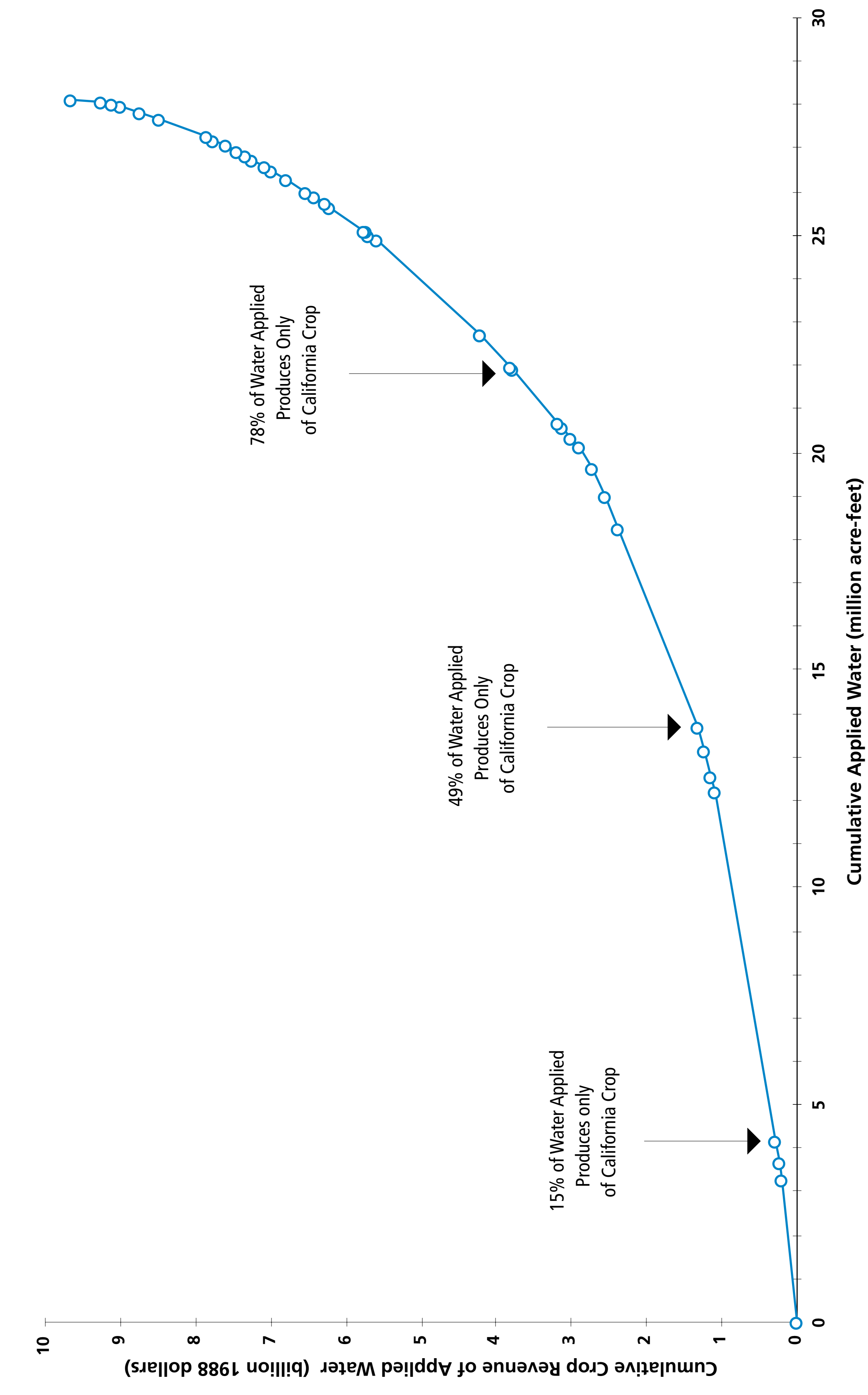
**Figure 9**

**1990 Consumed Water and Crop Revenue for Selected Crops**




[a] *Based on Pacific Institute calculations.* [b] *Derived from Zilberman et al. 1993.*

Figure 10
Cumulative Value of Applied Water in California Agriculture



available. Much of this groundwater is recharged during the wet seasons and long-term withdrawals can be sustained if careful management is maintained.

According to DWR estimates, yearly net groundwater extractions total about 8.5 maf in an average year and over 13 maf in a drought year (DWR 1993).[9] Gross groundwater extractions may be as high as 15 maf (DWR 1993), but lack of adequate monitoring data hinders accurate estimates. At present there is no statewide system to monitor and regulate groundwater use. Currently, only 13 out of 115 major groundwater basins have formal management structures in place, and only nine groundwater management agencies have been formed (DWR 1993). Only 37 percent of major groundwater basins have any form of management activity at all. State legislation (e.g., AB3030 The Groundwater Management Act of 1992) now allows local public water agencies to adopt groundwater management plans. Current methods of management include adjudication, coordinated agreements, special districts, and special act legislation (Neese 1994).

Some groundwater use poses a significant sustainability problem where overpumping occurs or where groundwater quality is threatened by the nature or scope of the withdrawal. Groundwater in the Sacramento/San Joaquin Valley is often pumped at rates that exceed the rate of natural recharge. According to the DWR, annual groundwater overdrafting in the early 1990s amounted to about 1.3 maf annually, and will continue for the foreseeable future. In the public draft of their long-term plan (DWR 1993), DWR estimated that in 2020 farmers would still be overdrafting ground water by 700,000 acre-feet per year, with an additional 200,000 af per year of ground water being degraded in quality in the San Joaquin Valley aquifers.[10] Most of the overdraft occurs in the Central Coast and Tulare Lake hydrologic study areas (HSAs), with continuing overdraft in the Sacramento River, South Lahontan, and Colorado River HSAs. While such overdraft in the short term may be sustainable if the groundwater tables are replenished in wet years, these estimates are for permanent average overdraft — an unsustainable practice for several reasons, including land subsidence and aquifer contamination.

Subsidence can occur where the land surface compacts and permanently lowers the storage capacity of the aquifer. In some locations in the San Joaquin Valley, land levels have fallen as much as 28 feet (AFT 1989). According to estimates from the U.S. Geological Survey (Bertoldi 1992), land subsidence due to groundwater overdraft in the Central Valley had already led by 1979 to the permanent loss of 20 million acre-feet of storage capacity. This old estimate needs to be updated.

Extended periods of overdraft can also result in the degradation of groundwater quality. Salt water intrusion — the inflow of sea water into coastal aquifers due to declining fresh water levels — is such an example. In Los Angeles and Monterey counties, sea water intrusion is already a problem. Overdraft can also accelerate the movement of contaminants existing within an aquifer. Further, serious problems may arise when overpumping draws pesticide and nitrogen-laden groundwater toward wells pumping water for human consumption. These problems already exist in several counties in the Tulare Lake region and other areas in the Central Valley. While the ill effects of groundwater contamination are not as permanent as those of land subsidence, cleaning up groundwater pollution is both difficult and expensive.

Chemical contamination of aquifers due to agricultural drainage is another ongoing, but unsustainable, dimension of the groundwater problem even when there is no overdrafting. Agricultural drainage is a problem particularly in the San Joaquin Valley, where large volumes of water applied for irrigation have occurred in an area with an impermeable clay layer. This layer makes a shallow groundwater table, necessitating the construction of

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9 Net groundwater withdrawals represent the difference between extraction and return seepage and is a measure of groundwater consumed. Gross groundwater extractions are total ground water pumped.

10 Explicitly, groundwater overdraft was eliminated from the final version of Bulletin 160-93 by simply removing it from estimated water "supplies." As a result, the already sizable gap between projected demand and supplies was made larger. The final report implies that groundwater overdraft will continue to be an important factor in meeting this gap, absent some unidentified substitute.

drainage systems to keep groundwater tables from coming too close to the surface where salts can leach out of accumulated irrigation water. The drainage water is heavily salinized and in some areas contains concentrated levels of naturally occurring selenium and molybdenum. These minerals are needed in trace amounts, but when concentrated in drain water cause problems for wildlife. The deformed birds found at Kesterson Wildlife Refuge are testimony to the effects of selenium poisoning (WEF 1991). These drainage related problems can also degrade soil quality — and ultimately crop yields — if water is applied and not drained.

The drainage problems on the westside of the San Joaquin Valley have been studied extensively in the last decade. The San Joaquin Drainage Program (1990) concluded that 75,000 acres of cropland should be retired by 2040, along with measures to improve efficiency to reduce drainage, reuse drainage water, dispose of drainage water, and better manage groundwater use. The experience of some of these districts has shown that tiered rate structures, where growers pay a higher price for increasing water use, can serve as an effective tool to both increase efficiency of irrigation water use and drainage (Thomas et al. 1990, Wichelns and Cone 1992).

Pollution from agricultural run-off is a much harder problem to deal with. Groundwater aquifers are being contaminated with nitrates from fertilizer use, and many surface water supplies are still so contaminated by agricultural chemicals that they cannot be used for any other purposes. Pesticide use also contributes to the chemical contamination of groundwater mentioned earlier. For example, the soil fumigant dibromochloropropane (DBCP) was banned in 1977, but it has consistently been found in Central Valley wells (AFT 1989).

***Increases in the human population over time have transformed California's Central Valley from the "Serengeti of North America" to the world's most productive agricultural region— a transformation that occurred with little respect or concern for the natural environment.***

Finally, there are direct links between water for the environment and water for agriculture. Under current policies, these links often lead to disputes and conflicts over how to value ecosystem health as opposed to agricultural production. There are many examples of policies that have developed water for irrigated agriculture at the direct expense of California's natural ecosystems, such as the damming of the San Joaquin river, the disaster at Kesterson, and the operation of the pumping plants in the Delta. Indeed, these conflicts are at the heart of many of the current debates over water in California and will have to be addressed in any comprehensive future agricultural strategy.

## D. ENVIRONMENTAL WATER USE TODAY

In an age before massive dams and aqueducts, California's rivers flowed uninterrupted into valleys, marshes, bays, and the ocean. Numerous rivers, lakes, and wetlands expanded and contracted with the seasons. These bodies of water supported an abundance of fish, game, and waterfowl, as well as numerous other animals and plants. Increases in the human population over time have transformed California's Central Valley from the "Serengeti of North America" to the world's most productive agricultural region — a transformation that occurred with little concern for the natural environment. The prevailing philosophy of the time has been to dominate nature, rather than to understand and co-exist in harmony with it. The result of this prevailing philosophy has been the sacrifice of much of California's natural environment and biological diversity due to a variety of social and economic forces (Jensen et al. 1993).

Ninety-five percent of California's wetlands have been lost. The state has lost more than 90 percent of its riparian forests in the Central Valley, 80 percent of its salmon and steelhead population since the 1950s, and 95 percent of the anadromous fish-spawning habitat in the Central Valley. No rivers are untouched by dams, reservoirs, or major water withdrawals for human use, including those that now have protection under federal and state law (California State Lands Commission 1993). Fish, considered to be excellent indicators of environmental conditions, have been badly affected. According to the California State Lands Commission report, over two-thirds of the 116 native California fish populations have declined sufficiently to raise concerns. California has lost at least 21 naturally spawning Pacific salmonid stocks, and an additional 39 are threatened. California State Lands Commission 1993). This decline is indicative of serious habitat degradation, as summarized in Table 12.

How and why did California sacrifice so much of its natural environment? What social, economic and legislative factors are responsible for these losses? Answers to these questions are not only essential to preserving what remains of California's natural environment, but to any effort to restore or enhance it as well. Until recently, only a small portion of the water used by fish, wetlands, migrating birds, and other environmental factors was explicitly included in state water management plans. Instead, water for human uses was identified and allocated and whatever was "left" was implicitly assumed to be available for the environment. The result of this approach was that the environment over time received a smaller and smaller share of the state's limited water. The severe impacts of water shortages on California's natural ecosystems in the last several years are the direct result of these policies (Nash 1993b, Gleick and Nash 1991, Thelander 1994).

Several legal and institutional mechanisms have recently been developed to try to protect California aquatic ecosystems and to explicitly reserve some water for those ends. The Federal and State Wild and Scenic Rivers acts protect some rivers in a relatively pristine condition. New wetlands policies try to limit development on the remaining five percent of California's original wetlands.

The Endangered Species Act requires explicit actions to protect endangered and threatened fish. And some innovative approaches to integrate agricultural and environmental concerns are being explored and implemented, such as flooding rice fields during the off-season to provide waterfowl habitat, reserving water for the environment whenever water transfers occur, and setting water quality and flow standards for the fragile Bay-Delta system. Without such creative and progressive policies, the revival of at least part of California's unique environment will not occur by 2020. (See the box: Summary of Environmental Water Requirements.)

*The Suisun Marsh is the largest remaining wetland on the west coast of the United States. (Courtesy of DWR.).*

*Many of California's wild salmon runs are extinct or threatened with destruction. (Courtesy of DWR.)*

## Table 12
## Changes in Aquatic and Other Ecosystems in California

| | Pre-Settlement Estimates | Current Estimates | Percentage Lost |
|---|---|---|---|
| Wetlands area in the Central Valley (acres)[a] | > 4 million | < 300,000 | 95% |
| Salmon and steelhead population[b] | N/A | N/A | 80% |
| Sacramento/San Joaquin salmon population[b] | 600,000 | 272,000 | 55% |
| Anadromous fish spawning habitat along rivers and streams in the Central Valley (miles)[b] | 6,000 | 300 | 95% |
| Riparian forest area in the Central Valley (acres)[b] | 922,000 | 102,000 | 89% |

*Sources:*

*[a] California State Lands Commission 1993; Ducks Unlimited 1994a and 1994b. Of the remaining wetlands, 30 percent are within the boundaries of National Wildlife Refuges and State Wildlife Areas, and 70 percent are privately owned and managed. Nationally, 75 percent of the remaining wetlands are privately owned.*

*[b] California State Lands Commission 1993. Of the 102,000 acres of riparian forest that remain, about half are in a highly degraded condition. The problem may be even worse, as reflected by the results when one uses the higher original riparian forest area estimate of 1.6 million acres (which means that we have lost approximately 94 percent).*

*N/A = not available*

## Summary of Environmental Water Requirements

**Wild and Scenic Rivers.** The Federal and State Wild and Scenic Rivers acts require that rivers that possess scenic, recreational, fishery, or wildlife values be preserved in a free-flowing condition for the benefit of the public. In 1990, California used 27.4 million acre-feet of water to meet existing fishery agreements, water rights, court decisions, and congressional directives. The vast majority of this water was simply water left in legally protected northern California rivers. Three regions used more than 98 percent of this water — the North Coast (18.8 million acre-feet in Wild and Scenic Rivers), the San Francisco Bay (4.6 million acre-feet), and the Sacramento River (about 3.4 million acre-feet). Very little additional water (just 300,000 acre-feet during an average year and 100,000 during a drought year) is currently allocated for instream use (DWR 1994a).

**Endangered Species.** The State and Federal Endangered Species acts set forth procedures for listing species as threatened or endangered, and require that no actions be taken to jeopardize the continued existence of the species or habitat critical for the survival of the species. The acts apply to government and private actions. Several recent listings will require re-allocation of water to the environment, but no good estimates of total amounts of water are available. New Congressional actions may threaten these environmental protections.

**Central Valley Project Improvement Act.** The CVPIA requires, among other things, that 800,000 acre-feet (af) of CVP water be provided for fish and wildlife restoration and 460,000 af for wildlife refuges and habitat areas in the Central Valley (Bobker 1995). These 460,000 af represent an additional 200,000 af of water over the 1990 level of water supply of these refuges (DWR 1994a).

**Wetlands.** There are approximately 300,000 acres of wetlands — state and federal refuges, private wetland preserves owned by nonprofit organizations, and private duck clubs — remaining in California (California State Lands Commission 1993). The DWR hopes to add an additional 225,000 acres of wetlands by 2010 (DWR 1994a). According to DWR data, in 1990 applied water use for wetlands was 1.4 maf for both average and drought years. Wetland water use, however, increases only to 1.7 maf for both average and drought years in 2000 and remains at that level through 2020 despite the goal to nearly double wetland areas by 2010.

**Bay/Delta Agreement.** The Bay/Delta agreement calls for the reallocation of up to 1.1 maf of water from agriculture and urban users for environmental use (Bobker 1995). Under the December 15, 1994 agreement, water reallocated under the agreement will initially be credited against the CVPIA environmental allocation.

### 1. Wetlands

Wetlands have historically been viewed as a resource to be converted to more "productive" uses. As recently as the 1970s, the federal Agricultural Stabilization and Conservation Services promoted drainage of wetlands through cost-sharing programs with farmers. Failure to quantify the real value of these natural resources resulted in significant losses. Nationally, more than half of U.S. wetlands have been lost, with an average loss of about 458,000 acres per year from the mid-1950s to the mid-1970s, 290,000 acres per year from 1974 to 1983, and 120,000 acres per year from 1982 to 1991 (GAO 1993). As bad as these losses have been nationally, conditions in California are even worse, with the state having lost approximately 95 percent of its wetlands (Emory 1994, J. Payne, Ducks Unlimited, personal communication, 1994). Migratory birds and waterfowl in California, which depend on these wetlands for food and habitat, have declined from an estimated 60 million in the late 1940s and 1950s to 12 million in the 1970s to just about 3 million in 1993.

Included in California's original wetlands inventory were large areas of inland wetlands in the Central Valley. These have been particularly hard-hit by agricultural and urban development along California's 7800 miles of rivers. At least 80 to 90 percent of riparian habitat has been eliminated, and the little remaining is threatened by urban development (California State Lands Commission 1993).

The "no net loss of wetlands" policy recently adopted by federal and state governments offers some hope that declines can be slowed or halted. Though new efforts to permit increased destruction of wetlands are being pushed in the 104th Congress, California's wetland policy establishes the goal of "no short-term net loss and an increase in wetlands in the long-term" (DWR 1994a). This shift in policy was prompted by the recognition that wetlands provide habitat for over half of all federally listed threatened or endangered species (DWR 1994a). Wetlands provide the principal habitat for waterfowl migrating along the Pacific Flyway, which extends from Canada to Mexico. Further, they provide spawning and rearing habitats for fish, provide flood control protection, improve water quality, recharge aquifers that serve urban and agricultural users, and support a multi-million dollar outdoor recreation industry.

In addition to protecting habitat, however, mechanisms must be developed to protect the water needed to keep these wetlands healthy. In one approach, the Central Valley Project Improvement Act of 1992, described in more detail below, requires the Secretary of the Interior to provide water for wildlife refuges and habitat in the Central Valley.

Managing wetlands better is only part of the solution. Improved watershed or "catchment area" management can also result in significant improvements in water quality in lakes and reservoirs, groundwater recharge, and flood protection. Because lakes, reservoirs, and rivers play an important role in California's environmental and economic well-being, it is important that their management be sustainable to preserve them for future generations.

## 2. Instream Flows: Release of Water for Fish

Sustainable water use requires that adequate flows, especially during critical periods, be maintained for the protection of stream, river, lake, and wetland ecosystems, as well as for instream human use. For wildlife, instream flows sustain the stream and floodplain riparian zones, and provide aquatic food resources. Not only do these flows provide food for fish and other species, but they also play a vital role in maintaining water quality and provide a corridor for migratory aquatic species to reach upstream spawning and rearing habitat.

Because agriculture uses nearly 75 percent of developed water resources in an average year and even more in drought years, releases of water from lakes and reservoirs are usually timed to coincide with crop demand, not ecosystem requirements. Steelhead were once found in all coastal rivers, but now approximately 90 percent of the state's remaining wild steelhead are found north of San Francisco. The construction of large dams on major rivers has caused a 95 percent reduction in the historic salmon and steelhead spawning habitat in the Central Valley river system (California State Lands Commission 1993).

*The Gray Lodge Wildlife Refuge in the Central Valley is one of the few places in California where masses of waterfowl still congregate in winter. (Photo: P. Gleick)*

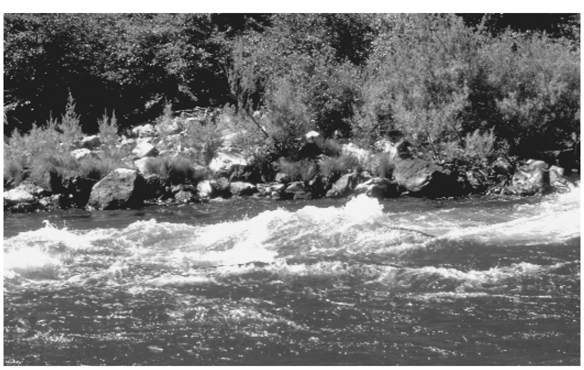
The most dramatic example of the impacts of dams on salmon is Friant Dam on the San Joaquin River. The dam's construction resulted in the extinction of the largest spring-run chinook population in the state. The dam blocked upstream spawning grounds and reduced spring, summer, and fall flows below the dam to a minimum. Every year the riverbed upstream of the Mendota pool in Fresno County dries up (California State Lands Commission 1993). To avoid an ESA listing of the surviving chinook salmon populations, the U.S. Fish and Wildlife Services (FWS) and the California Department of Fish and Game (DFG) have established that increased minimum flows (and decreased export levels) are required in the Sacramento and San Joaquin Rivers. Currently, the Bureau of Reclamation and Fish and Wildlife Services, pursuant to section 3406 of the Central Valley Project Improvement Act, are conducting a Comprehensive Plan of the San Joaquin River. The objective of the plan is to identify actions to restore and enhance San Joaquin River fish, wildlife, and habitat. Plan findings will be used to make recommendations to Congress on how to manage and allocate water resources of the San Joaquin River and to try to meet the CVPIA's goal of doubling the anadromous fish populations (USBR and FWS 1994). Ultimately, Congressional approval is required before any water is released to restore the San Joaquin river fisheries.

Agricultural drainage contaminated by fertilizers and pesticides also poses a direct threat to fish and wildlife habitats and the species that depend on them. In 1990, for example, California farmers used over 163 million pounds of pesticides and herbicides, nearly one-third of all pesticide use in the United States (California State Lands Commission 1993). A recent study conducted by the U.S. Fish and Wildlife Services concluded that agricultural return flows, contaminated with excess nutrients, pesticides, herbicides, and sediments, are the most common pollution sources affecting wildlife refuges. According to the State Water Resources Control Board, agriculture contributes more than 58 percent of the pollution to California's rivers statewide (California State Lands Commission 1993).

The need to reduce non-point source pollution, particularly agricultural pollution, is widely recognized. A recent study estimated that meeting water quality standards in some places will require reducing annual pollution loads from farm drainage by as much as 80 to 90 percent, depending on river flow conditions (Young and Congdon 1994). The U.S. EPA, with the assistance of other government agencies and the environmental community is in the process of developing non-point source water pollution standards.

### 3. Wild and Scenic Rivers

Under the National Wild and Scenic Rivers Act, passed in 1968, rivers that possess "outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural, or other similar values" are preserved in their free-flowing condition. The Act establishes as national policy that "dam and other construction at appropriate sections of rivers of the United States needs to be complemented by … preser[vation of] other selected rivers … in their free-flowing condition." Just four year later (1972), California passed the State Wild and Scenic Rivers Act to preserve free-flowing rivers that possess "extraordinary scenic, recreational, fishery, or wildlife values." The Act authorized diversions needed to supply domestic water to residents of counties through which the river flows only if the Secretary of the Resources Agency determines that the diversions will not adversely affect the river's free-flowing character.



*Portions of the Klamath River are protected by the State Wild and Scenic Rivers Act. (Photo: P. Gleick)*

The California rivers included in the National Wild and Scenic Rivers system are the Middle Fork Feather, North Fork American, Tuolumne, Merced, Kings, North Fork Kern, South Fork Kern, Smith, Sisquoc, and Big Sur Rivers, and Sespe Creek. The rivers included in the State Wild and Scenic Rivers system are the Klamath, Scott, Salmon, Trinity, Smith, Eel, Van Duzen, American, West Walker, and East Fork of the Carson. The main difference between the national and state acts is that the federal government can override the state designation (i.e., the Federal Energy Regulatory Commission can still issue a license to build a dam on a river designated wild and scenic under the state act). This difference explains why national wild and scenic designation is preferred (DWR 1994a).

### 4. Endangered Species Act (ESA)

#### *a) Federal*

The ESA is designed to preserve endangered and threatened species by protecting individuals of the species and their habitat, and by implementing measures that promote their recovery. The federal ESA defines an endangered species as one that is in danger of extinction in all or a significant part of its range. It defines a threatened species as one that is likely to become endangered in the near future. Presently, 115 species native to California have been listed threatened or endangered — the largest number in any state (DWR 1994a, Thelander 1994).

Once a species has been listed, no federal action may be taken that jeopardizes the continued existence of the species or habitat critical for the survival of that species. The ESA also applies to new and ongoing actions by state agencies and private parties.

#### *b) California*

The California Endangered Species Act also requires that proposed actions not jeopardize a listed species. If a potential action will jeopardize a listed species, state agencies must adopt reasonable alternatives unless there are overriding social or economic conditions that make such alternatives infeasible.

Although ESA requirements seem harsh to some, mitigation and project modification through long-term planning can allow landowners to continue their activities with minimal impact to endangered species. In many instances, habitat enhancement can actually help farmers. Restoring and preserving natural habitat invites predators large and small to come to the farm, aiding farmers with pest control. Also, by preserving habitat along and within farmland, the ESA can slow the encroachment of urban areas into rural space.

In addition to long-term habitat conservation planning, "mitigation banking" has been used to deal with land-use conflicts. Under this process, anyone interested in developing previously undisturbed habitat occupied by a protected species pays a premium. The revenues go into a fund that makes possible the purchase of better habitat for the species elsewhere. Such a process has the potential to preserve more habitat for endangered or threatened species, while at the same time minimizing the economic impacts on developers and farmers.

## 5. Innovative Environmental-Agricultural Water Collaborations

Recently, efforts have been made to develop innovative ways of reducing the tensions between agricultural and environmental interests. Some efforts in this area began with Congressional works such as the Conservation Reserve Program, the Conservation Compliance, the Wetland Reserve Program, and other aspects of the federal Farm Bill. Another program, the Agricultural Conservation Program (ACP) coordinated by the U.S. Department of Agriculture, provides cost-share money to landowners for creating or enhancing habitat. The expressed purpose of the assistance is to facilitate the restoration, preservation, and enhancement of wildlife habitat. Efforts under this program include the planting of hedgerows, revegetating along canals ditches, setting aside acreage for native vegetation, and creating or enhancing wetlands.

California agricultural interests have also recently tried some innovative new programs to enhance wildlife habitat while maintaining agricultural productivity. Because most of the Central Valley is privately owned, restoring a substantial amount of agricultural land to its natural state to preserve or enhance waterfowl populations is unlikely. As a result, efforts to preserve and restore wildlife must focus on ways of modifying agricultural practices in order to provide greater wildlife habitat value while leaving agricultural land in private ownership and in agricultural production. Recent innovations within the California rice industry are good examples.

### *a) Flooding Rice Fields for Seasonal Wetlands*

With California's wetlands and marshes now almost completely drained to make room for agriculture, the need to preserve and restore habitat for threatened or endangered species is critical. Rice farmers, long considered the enemy by environmentalists for destroying wetlands and the burning of rice straw, are now working to provide seasonal habitat for waterfowl and other species and to reduce water use, pesticide use, and air pollution. Measures to modify agricultural practices, such as flooding rice fields to produce seasonal wetlands for waterfowl, may come to provide an important mitigation option for the extensive loss of natural wetland habitats.

The practice of flooding rice fields not only provides habitat for migratory waterfowl, birds, and other species, but also benefits rice farmers. Rice farmers receive large amounts of free natural fertilizer left behind in the droppings of these feeding flocks. Most importantly, by flooding their fields after harvest, rice farmers comply with state and federal air quality laws that would otherwise force them to decrease acreage or stop farming altogether. Some concern has been raised about negative impacts on fish populations and other instream uses, and extensive use of the practice should be carefully evaluated (R. Weiner, Natural Resources Defense Council, personal communication, 1995).

*Flooded rice field in the northern Sacramento Valley can, in the right circumstances, also provide habitat for waterfowl. (Photo: P. Gleick)*

## Case Study: Flooding Rice Fields

Allen Garcia, a rice farmer in Yolo County, has long been guided by a personal philosophy to minimize the impact on the environment and to return organic matter to the soil. Driven by personal values and the recognition of the substantial loss of wetlands and dramatic declines in waterfowl in the Central Valley, he was one of the first to flood his rice fields to provide food and habitat for waterfowl. The flooding of rice fields caught the attention of corporate rice farmers and the rice industry commissioned several studies to analyze the benefits. These studies found that the flooding of rice fields provides large quantities of food and outstanding habitat for migratory waterfowl and shorebirds, while also providing natural fertilizers for the fields and reducing conflicts with state and federal air quality laws (Western Ecological Services Company 1991, 1994).

According to field experience, flooding rice paddies between plantings provides about 600 pounds of food per acre for waterfowl — 300 pounds of carbohydrates (straw and grain left over after harvest) and 300 pounds of invertebrates (A. Garcia, rice farmer, personal communication, 1994). This estimate is consistent with the estimate of 500 to 600 pounds of food per acre — 246 to 346 pounds of waste rice per acre and 250 pounds of invertebrates — reported by the California Rice Industry (Western Ecological Services Company 1991).

### *b) Yolo County Resources Conservation District*

Conventional farming practices coupled with structural flood control measures to meet municipal interests, have adversely affected wildlife habitat. Through progressive land-use and agricultural programs, the Yolo County Resources Conservation District (YCRCD et al. 1994) is working to reverse the loss of habitat and diversity, both in wildlife and plant species. The YCRCD provides technical assistance through its habitat corridor program to farmers interested in creating wildlife habitat within farming operations. In addition, it is conducting a study to determine the feasibility of integrating water-system management through the local irrigation district in order to provide on-farm habitat, wetland development, improved water quality, and enhanced groundwater recharge.

Because taking private agricultural land out of production is a controversial option, the YCRCD advocates changing agricultural production practices to provide greater habitat value while still allowing crop production to continue, such as through the creation of habitat corridor systems. A habitat corridor of restored natural vegetation along roadsides, berms, ditch banks, canals, and field borders can provide year-round habitat for wildlife without having negative impacts on farming practices.

The YCRCD is working to transform miles of barren irrigation canal banks into native grass habitat zones or corridors to reduce canal erosion and populations of noxious weeds. These corridors are intended to provide escape and forage areas for small mammals, reptiles, birds, and beneficial insects, while retaining agricultural land in private ownership and in agricultural production. Restoring and preserving such habitats encourages predators to come to the farm, aiding farmers with pest control. Early results show that such habitat corridors reduce pests and noxious weeds, curtailing the need to apply pesticides and herbicides (YCRCD et al. 1994).

Other farming options being studied and slowly implemented include row crop tailwater ponds, integrated management techniques that meet diverse interests including development of on-farm habitat, wetland development, protection of water quality, and enhanced groundwater recharge (Anderson 1994, YCRCD et al. 1994). Cooperating landowners have already created more than 20 functional and cost-effective impoundments and the potential to establish hundreds more exists. The YCRCD is also working to enlist rice farmers to manage their land to provide stormwater storage, groundwater recharge, and seasonal wetlands as well as to produce rice (see rice section above).

### *c) Cover Cropping*

A three-year pilot project on cover cropping is currently underway in the state of Washington to reduce the nitrate concentration in ground water and to provide seasonal habitat and food for migrating waterfowl and birds in regions where nitrates seep into the soil, such as with pea farms. Ducks Unlimited saw the farmers' plight as an opportunity to solve two problems—water quality degradation and loss of habitat for waterfowl and other migrant birds.

After studies revealed that barley reduces the nitrate concentration in the soil, a pilot program was developed by Ducks Unlimited to grow an early crop of peas followed by a cover crop of barley. Ducks Unlimited pays participants to grow an early cash crop of peas, and to leave the barley as a cover crop for the waterfowl and birds (J. Payne, Ducks Unlimited, personal communication, 1994). The benefits of the pilot project have not been fully analyzed, but preliminary results show reductions in nitrate concentrations, improvements in water quality, and increases in bird populations.

## 6. Historical Overview of the Bay/Delta Estuary

The two great rivers of the Central Valley — the Sacramento and San Joaquin — meet the Pacific Ocean at the Bay-Delta Estuary. This estuary has also been the center of many water battles for the last two decades. Properly known as the San Francisco Bay/Sacramento-San Joaquin Delta Estuary, this waterway sees the outflow of 47 percent of the state's total surface water runoff and provides freshwater to over 20 million of the state's residents. Because the Estuary is where fresh water meets salt water, it also provides diverse habitats rich in nutrients, and it supports over 120 species of recreational and commercial fish. It is an important wintering site for migratory waterfowl and a vital spawning grounds for anadromous fish. The Bay-Delta contains the largest wetland habitat in the western U.S.

The Estuary has undergone great changes ever since Europeans settled in California. Gold mining in the latter half of the 19th century sent 1 billion cubic yards of sediments downstream through the Estuary. Between 85 to 95 percent of the Estuary's wetlands have been filled in or altered. The Central Valley Project and State Water Project now divert almost 20 percent of the normal inflow to the Delta in an average water year and a substantially larger fraction in dry years. These water diversions—and their impacts on fisheries and wildlife — are the cause of most of the controversy over the Bay-Delta. Pumping of water south through the Delta has changed the natural variations of freshwater flow to the ocean and in particular has changed the salt balance. Further, pollution from growing urban areas and the introduction of exotic species in the Estuary are threatening the estuarine ecosystem, as shown by the recent need to list the Delta smelt and winter-run chinook salmon as threatened or endangered species.

The State Water Resources Control Board (SWRCB) has jurisdiction over water requirements for the Bay-Delta through its water rights process. In 1978, SWRCB's Decision 1485 set standards for protecting water quality, limiting water exports from the Delta, and setting minimum flow rates. The goal of the standards was to maintain water quality at the level it would have been without federal and state water diversions. By the early 1980s, however, it was clear that the standards that had been set were inadequate and the decision was challenged and overturned in court in 1984. Hearings to adopt new standards began in 1987. During these hearings, more than 150 interests and state and federal agencies testified, and the SWRCB released a draft plan in 1988, which it then subsequently withdrew. In 1991, the Board adopted a salinity plan and began work on a water rights decision. In 1992, interim standards were set under Decision 1630, but again, this set of standards was withdrawn at the request of Governor Wilson. The U.S. Environmental Protection Agency then developed standards in December 1993. The showdown between the state and federal agencies was partly resolved in December 1994 when both sides agreed to a compromise set of standards and practices for an interim period of three years, with the intention of developing plans for the long-term management of the resource.

## 7. The Central Valley Project Improvement Act of 1992

One of the major pieces of federal legislation affecting California water in the last decade is the 1992 Central Valley Project Improvement Act (CVPIA) (PL 102-575). The CVPIA specifically sets aside water for environmental restoration purposes. The Act allocates 800,000 af per year of water for fish and wildlife purposes, establishes a goal of doubling anadromous fish populations (over average levels between 1967 and 1991) by 2002 in Central Valley rivers and streams, and dedicates an additional 460,000 af per year for wildlife refuges and habitat areas in the Central Valley and for Trinity River instream flows. This water is given priority over agricultural contract water and is subject only to 25 percent maximum cutback. The Act also requires that a comprehensive plan be developed for the restoration of anadromous fisheries in parts of the San Joaquin River. To carry out restoration projects, a $50 million per year Restoration Fund was established and funded by charges on water users and on water transferred to non-CVP users (PL 102-575).

The CVPIA changes some of the restrictions on CVP contractors. Of particular significance is that water is now allowed to be transferred outside of CVP service areas if there is a willing buyer and seller. A transfer fee of $25 per acre-foot raises money for the Restoration Fund. No new contracts for CVP water are allowed until a programmatic Environmental Impact Statement is completed on the effects of the Act.

### 8. Water Banks

Droughts cause hardship for all water users in the state, but perhaps their greatest impacts fall on ecosystems (Gleick and Nash 1991, Nash 1993b). Recent innovative programs, such as the Drought Water Bank of 1991 and 1992, show that with proper planning, some of the impacts on human users can be mitigated or prevented. In 1991, the DWR's Bank purchased 820,000 af of water — about half from the fallowing of agricultural land, a third from the substitution of ground water for surface supplies, and the rest from stored water supplies. The Bank bought water at a set price of $125 per af and sold it to areas of critical need at $175 per af, excluding delivery costs from the Delta (DWR 1992).

*Droughts cause hardship for all water users in the state, but perhaps their greatest impacts fall on ecosystems.*

Creative efforts to alleviate the negative impacts of the drought, such as the Water Bank, should also be applied to ecosystems. While ecosystems undergo natural variations in flow, human diversions can exacerbate these variations. Future water banks could follow similar tactics as the CVPIA to help protect ecosystems. For example, the state could charge a transfer fee that can be used to buy water for critical ecosystem needs. Or a certain percentage of the water bought by the Bank could be dedicated to environmental purposes. The Department of Fish and Game has already been buying water in the short term for wildlife refuges and fishery purposes (DWR 1994a).

## E. LESSONS FROM EXTREME WEATHER CONDITIONS

There is growing concern among climatologists and meteorologists that the world is beginning to experience increasingly severe weather patterns. Floods and droughts — a natural consequence of climatic variability — have occurred since the beginning of time, as chronicled in the book of Genesis, in the many myths, legends, and histories that survive from ancient times, and in the geophysical record. It is as true today, as it was then, that heavy precipitation can overtax inadequate local drainage systems and result in flooding outside of normal floodplains, while droughts can cripple food production and lead to widespread social disruption. Historically, government policy to reduce flood and drought losses have focused on the construction of physical measures such as building dams, levees, and other structures to hold back flood waters and to increase reliability of supply. An unintended side-effect of government-funded flood- and drought-protection measures was that they accelerated the development and urbanization of the floodplains putting more property and people at risk, at the expense of the environment. Thus, despite the billions of dollars in federal investments in structural projects, flood and drought losses and disaster-relief costs continue to rise (FIFMTF 1992).

### 1. California's Flood Experience

Just weeks before California's 1995 winter floods began, forecasters were predicting a dryer-than-normal winter. In December 1994, the National Oceanic and Atmospheric Administration published one scientific team's forecast that California would experience less than 75 percent of its normal rainfall level through February 1995 (The Gazette 1995). This inability to accurately forecast climatic extremes is a normal characteristic of meteorology and makes it vital that society look at ways of reducing vulnerability to such extremes.

Are traditional methods of reducing risks of flooding working? Despite the billions of dollars in public infrastructure expenditures for flood protection, floods will continue and, as more and more people make their homes in floodplains, damages will continue to skyrocket. As floodplains are developed for urban and agricultural purposes, the resources and services they provide in their natural state are reduced. Natural floodplains provide floodwater storage and pathways, groundwater recharge, water-quality enhancement, aesthetic and cultural values, and habitat for scarce, threatened, or endangered plants and animals. Private interests develop the land to maximize the owners' economic return, generally in a fashion that degrades natural values and increases later public expenditures for relief, rehabilitation, and/or corrective action. Government programs, however well intention, often encourage such development (NHRAIC 1992). According to the 1992 Federal Interagency Floodplain Management Task Force report, compliance with federal, state, and local standards have a potentially greater impact on flood loss reduction than any other single floodplain management tool (FIFMTF 1992). The Congress in 1982 made a specific finding that annual losses from floods are increasing and attributes the increase primarily to acceleration of development and habitation of flood-prone areas (Singer 1990). Given the current Congressional debate on land-use and environmental standards, however, the direction of future federal, state, and local governments controls over the further development of floodplains is uncertain.

By mid-March 1995 California floods had caused $3.3 billion in damage — $1.3 billion from the January floods and $2.0 billion from the early March floods (FEMA 1995; Associated Press 1995). Agricultural damage estimates at this point totaled nearly $500 million — $97 million from January's storms and $360 from the early March storms. As of mid-March, 53 of California's 58 counties were classified as disaster areas. Crop damages in California's rich Salinas Valley, called the nation's salad bowl, exceeded $220 million for the March rains alone (Howe 1995). Subsequent rains and the melting of the large Sierra Nevada snowpack may cause further flooding and damages.

*California is subject to both severe droughts and floods. In early 1995, several parts of the state were flooded after record rains. (Courtesy of DWR.)*

In the floodplains, flooding is a normal event in the cycle of life. Floods can provide access to food and enhanced habitat for fish, birds, and other wildlife. Floods are not only beneficial, but may even be necessary to restore degraded ecosystems, such as washing out the upper part of the San Francisco Bay estuary with flows that may be 15 times higher than drought flows — estimates of the March flows are around 350,000 cubic feet per second (All Things Considered 1995).

But as the waters recede, human and wildlife populations face serious environmental problems that could haunt California for years to come. As with the 1993 Mississippi floods, the more troubling question is what becomes of the industrial toxic pollutants, agricultural pesticide runoff, and raw sewage that were carried by floodwaters (Kriz 1993). Of critical importance to California's economy, to the magnitude of future flood impacts, and to remaining fragile wildlife is the type of recovery policies the federal, state, and local governments implement over the next year.

To expedite cleanup of California's 1995 flood-ravaged farmlands and communities, Governor Wilson moved to exempt emergency flood repairs from the state's Endangered Species Act (ESA). He also loosened restrictions on agriculture burn days through the California Air Resources Board, to allow farmers more flexibility in disposing of flood debris. The Governor's decision, made in the context of a possible run for President, appear to authorize people to take action without regard to whether they are killing endangered species if the actions are designed for flood, fire control, security, or a range of other purposes (BNA 1995; Anderluh 1995). Whether or not these actions are legal is not yet certain.

Several months of unplanned and uncoordinated action, in the name of disaster recovery, could undermine years of environmental protection and investment. The state must work to balance short-term disaster recovery and long-term protection of both the environment and future developments. California should follow the lead established after the 1993 Mississippi floods and consider long-term flood management alternatives, such as expanding wetlands areas and restoring watersheds, moving communities out of floodplains, and restructuring the most vulnerable levees. In addition, to discourage further urbanization of the floodplains California should not continue to subsidize new developments, nor provide below market rate insurance policies.

## 2. California's Drought Experience

While floods can cause significant loss of life and damage to property, droughts are far more likely to prompt concern over water supplies and changes in the way water is managed. Two recent droughts have contributed to changing public opinion about California water resources. They also had dramatic effects on the state's average urban per-capita water use (see Figure 11). As illustrated by this figure, large temporary reductions in per-capita water use can be achieved during drought years when aggressive short-term conservation and rationing programs are in effect. More lasting reductions in per-capita water use will come about through permanent water conservation and education programs, water-efficiency mandates, and other factors.

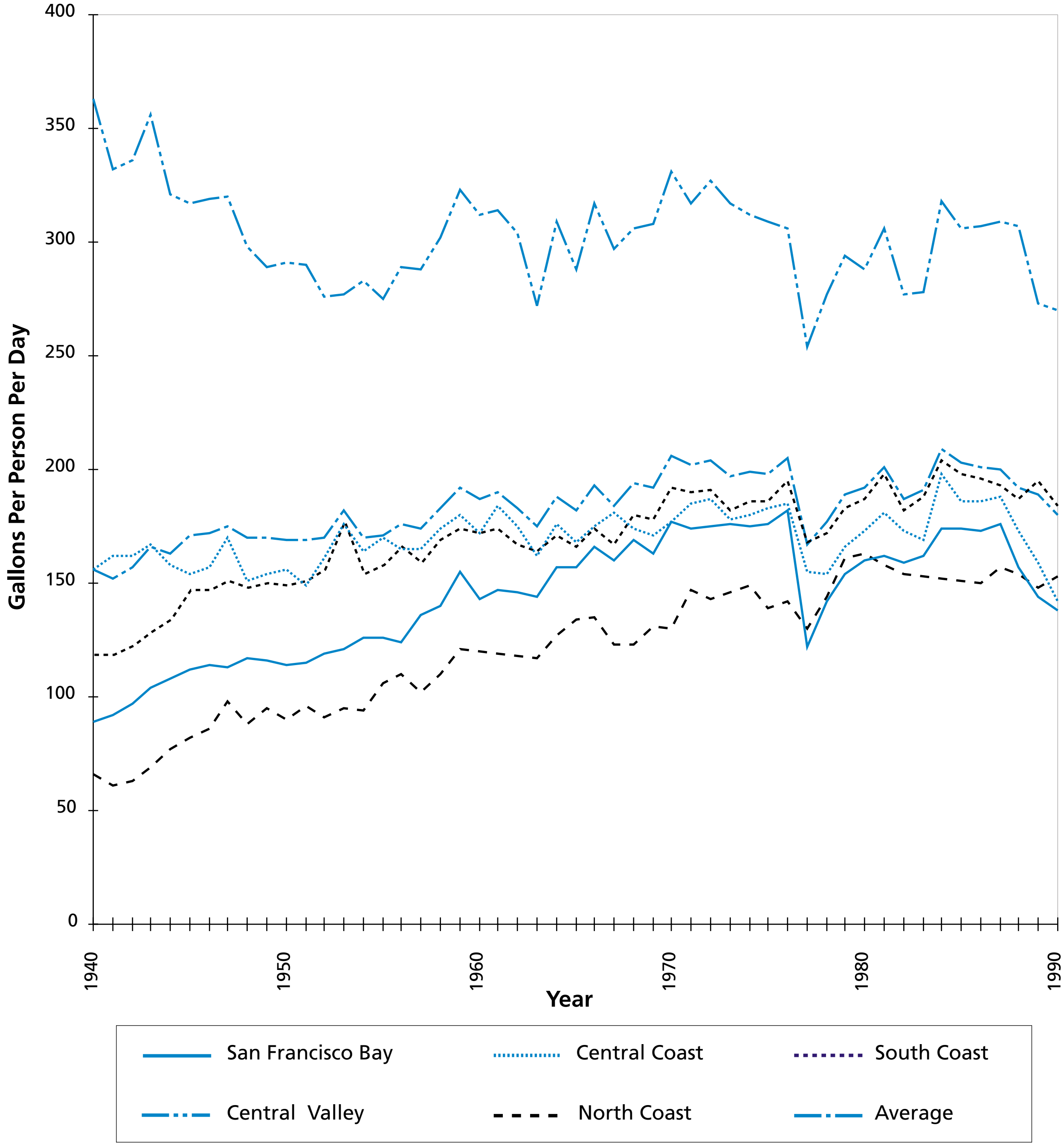
The drought of 1976 and 1977 was the most severe two-year drought in the past century. This drought not only revealed the vulnerability of the state's large reservoirs to persistent water shortages, but was a turning point for urban water policy. For the first time, urban water use became the subject of wide public debate. Water agencies began to promote water efficiency and conservation measures as an alternative to building new supply. In the early 1980s, California passed the first water-efficiency standards for toilets, faucets, and showerheads. While there was substantial concern over urban water use immediately following the drought, it was not long before most government agencies, water utilities, and the public return to business as usual.

The 1987-92 drought, the longest and deepest droughts in recorded history, once again revealed the state's vulnerability to water shortages. For six years, average runoff was roughly half of normal, the state's enormous reservoirs were drained nearly dry, and water users found themselves in the midst of new calls for voluntary or mandatory cutbacks in use. The drought produced criticism and re-evaluation of nearly all forms of water use, from agricultural practices to environmental water uses. Not surprisingly, the drought also focused attention on the mismanagement of urban and agricultural water resources and on the need for policies to improve water-use efficiency (Moore et al. 1993).

The 1987-1992 drought provided an opportunity to see how water cutbacks affected agriculture. Total water deliveries from the Central Valley Project decreased 35 percent between the period from 1987-89 to the 1990-91 period. In the same period deliveries from the State Water Project decreased 55 percent. In the state as a whole, there was a nine percent decrease in supply. A survey of 135 water districts throughout the state, including 60 percent of Central Valley districts, found that the main responses to the cutbacks included increased groundwater pumping, changing crop types or fallowing land, and adjusting irrigation management. Groundwater pumping was found to have increased 72 percent among districts surveyed, from 425,000 acre-feet in 1987 to 923,000 acre-feet in 1991 (Zilberman et al. 1992). Total fallowed land in these districts increased 23 percent, from 259,000 acres in 1987 to 397,000 in 1991. Interestingly, agricultural revenues during the drought actually increased slightly as larger sales of higher valued crops made up for lower production of other crops and as crop prices remained firm.

Irrigation management also changed in this

**Figure 11**
**Urban Per-Capita Applied Water Use in Selected Hydrologic Regions**




*Source: DWR 1994a.*

period. Farmers shortened furrow runs, used sprinkler systems for early irrigation, stressed crops, and installed tailwater return systems. In some cases, new irrigation technologies were adopted for higher value crops. Thirty-five percent of farmers in responding districts installed new sprinklers, and 33 percent installed new drip irrigation. Institutional responses on the part of water districts included pricing changes (49 percent), changes in allocation schedule (53 percent), and increased voluntary market transfers (52 percent of districts) (Zilberman et al. 1993). Overall, the agricultural community proved remarkably resilient to the drought.

There is also substantial flexibility in the residential sector, as shown by the water savings achieved in many communities during the more recent 1987-1992 drought. During the fifth year of drought, residents of a number of coastal cities achieved substantially higher conservation than requested by the municipalities, as illustrated in Table 13. Some of these savings are relatively permanent, such as fixture changes and xeriscaping program.

**Table 13**
**Water Conservation Experiences of California Municipal Agencies During the 1987 to 1992 Drought**

| | Conservation Requested [a] | Conservation Achieved [a] |
|---|---|---|
| East Bay Municipal Utility District | 15% | 25% |
| Marin Municipal Water District | 25% | 35% |
| Monterey Peninsula Water Management District | 20% | 31% |
| San Francisco Water Department | 25% | 33% |
| Santa Clara Valley Water District | 25% | 32% |

*[a] Water use reductions in 1991, as a percentage of the 1986-87 water year.*
*Source: Burton 1992.*

## 3. Past and Future Climates in California

We have only a limited understanding of past climatic conditions and some tentative hints about future ones. The instrumental record — the period of time when instruments recorded different aspects of the climate — rarely extends back 100 years. In many regions, and for many climatic variables, even far less information is available. Several methods are used to try to reconstruct older climatic conditions. These include a variety of "paleoclimatic" techniques such as measuring tree rings, evaluating pollen samples, looking at sediment distributions, and so on. In California, several important paleoclimatic studies have been done that give clear indications of severe droughts as far back as the mid-1500s.

Earle and Fritts (1986) and others (SSDP 1991) used tree-ring data to reconstruct the drought record in parts of California from 1560 to 1980 AD. According to their studies, the most severe drought in northern California since 1560 is considered to be the period from 1929 to 1935. The most recent 1987 to 1994 drought is comparable with this late-1920s to early-1930s drought in both duration and magnitude.

Recently, there has been growing concern about the possibility of global climatic changes associated with growing atmospheric concentrations of greenhouse gases (see Box: Future Climatic Changes). Despite many remaining scientific uncertainties, there is now a strong consensus that the continued buildup of greenhouse gases in the atmosphere will lead to higher global average temperatures and some significant changes in the hydrologic cycle, including precipitation patterns and storm frequencies and intensities. Among the possibilities are a higher frequency of extreme events, including both floods and droughts. Recent hydrologic experience in California, with a long drought and some severely wet years, suggests the urgency of addressing the remaining uncertainties. The possibility of these changes makes it urgent that managers and institutions begin to think about how to manage water resources under different climatic conditions.

## Future Climatic Changes

Our understanding of global climatic conditions has improved in the last several years, leading to the concern that we are unintentionally modifying the climate in ways that may already be noticeable and will certainly become noticeable in the next several decades if no actions are taken. The problem of global climatic change, or the "greenhouse effect," makes the problem of hydrologic prediction even more uncertain than it already is. All traditional hydrologic tools for evaluating the frequency and magnitude of extreme events assume that future conditions will look like past conditions. Global climatic changes, however, have the potential to significantly alter both the intensity and magnitude of climatic events in California, leading to new and unanticipated climatic regimes. While there is a broad scientific consensus that global climatic change is a real problem and that it will alter the hydrologic cycle in a variety of ways, there is little certainty about the form these changes will take, or when they will be unambiguously detected. As a result, while we can expect global climatic changes to begin to appear within the next several decades, or even earlier, we are unable as of yet to determine how such changes will affect water-supply systems. Among the principal conclusions of a multi-year international scientific assessment about the state of knowledge about global climatic change (IPCC 1990) were:

"We are certain of the following:

> emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases: carbon dioxide, methane, chlorofluorocarbons (CFCs) and nitrous oxide. These increases will enhance the greenhouse effect, resulting on average in an additional warming of the Earth's surface.

"We calculate with confidence that:

> Continued emissions of these gases at present rates would commit us to increased concentrations for centuries ahead. The longer emissions continue to increase at present day rates, the greater reductions would have to be for concentrations to stabilize at a given level. (IPCC 1990.)

The implications of these climate changes for water resources are highly uncertain, because of limitations of the large climate models in evaluating regional impacts. In spite of these uncertainties, the Second World Climate Conference, held in Geneva in late 1990, concluded:

> "The design of many costly structures to store and convey water, from large dams to small drainage facilities, is based on analyses of past records of climatic and hydrologic parameters. Some of these structures are designed to last 50 to 100 years or even longer. *Records of past climate and hydrological conditions may no longer be a reliable guide to the future. The design and management of both structural and non-structural water resource systems should allow for the possible effects of climate change.*" *(Italics added)* (Proceedings of the Second World Climate Conference, Jäger and Ferguson 1991.)

A separate study published in 1990 focused on the implications of global climate changes for the water resources of the United States. This study, entitled Climate Change and U.S. Water Resources and published by J. Wiley and Sons, New York, 1990 for the American Association for the Advancement of Science concluded:

> "Among the climatic changes that governments and other public bodies are likely to encounter are rising temperatures, increasing evapotranspiration, earlier melting of snowpacks, new seasonal cycles of runoff, altered frequency of extreme events, and rising sea level . . . *Governments at all levels should reevaluate legal, technical, and economic procedures for managing water resources in the light of climate changes that are highly likely." [Italics in original.]*

Finally, the international treaty covering global climatic change, the United Nations Framework Convention on Climate Change (1992), states in Article 3.3 that the Parties to the Convention:

> "should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures should be cost-effective."