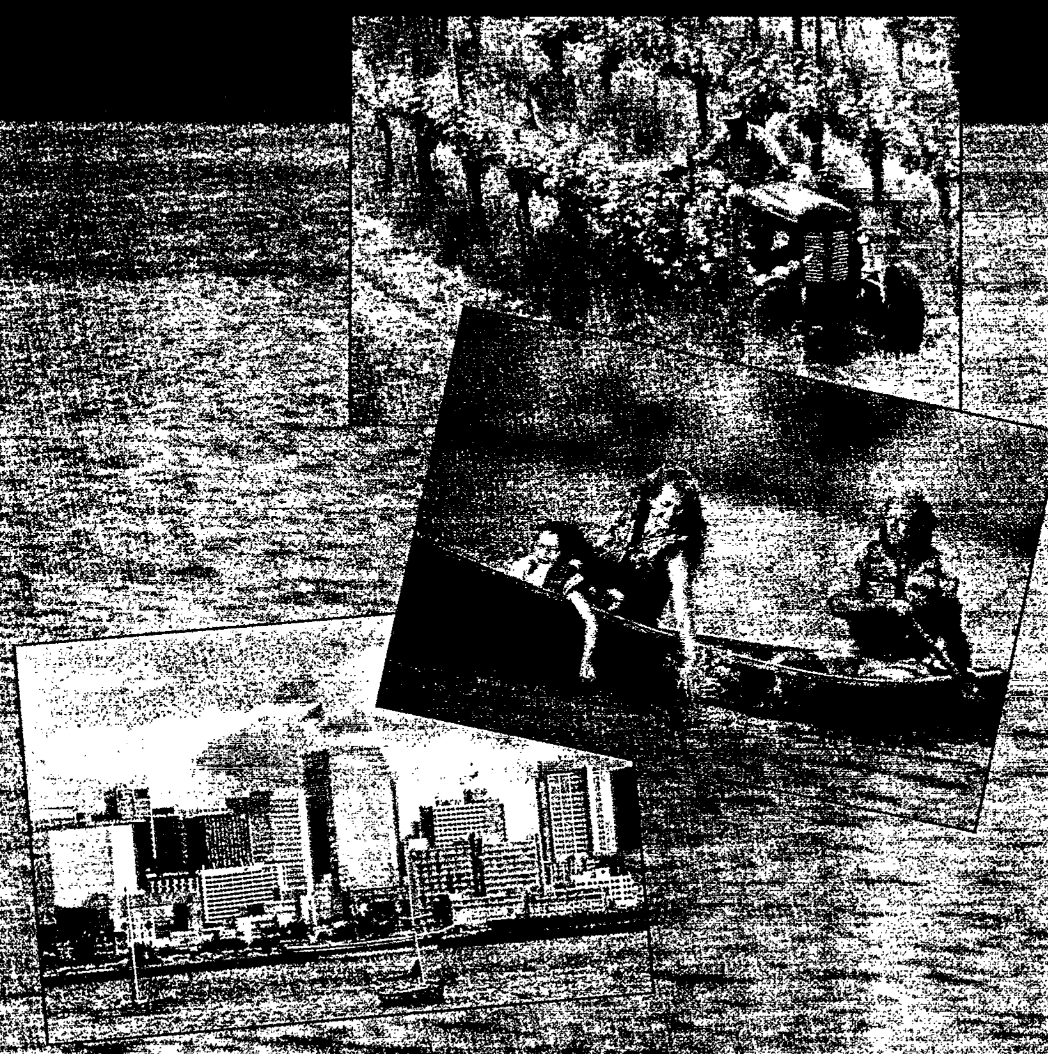
California Water 2020
A Sustainable Vision



PACIFIC INSTITUTE
FOR STUDIES IN DEVELOPMENT, ENVIRONMENT, AND SECURITY

California Water 2020
A Sustainable Vision

Peter H. Gleick
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About the Pacific Institute

The Pacific Institute for Studies in Development, Environment, and Security is an independent, non-profit center created in 1987 to pursue research and policy analysis in the areas of environment, sustainable development, and international security. Underlying all of the Institute's work is the recognition that the pressing problems of environmental degradation, regional and global poverty, and political tension and conflict are fundamentally interrelated, and that long-term solutions must consider these issues in an interdisciplinary manner. The Pacific Institute strives to improve policy through solid research and consistent dialogue with policy makers and action-oriented groups, both domestic and international.

The Institute has three broad goals: (1) to conduct policy-relevant research on the connections among environmental change, economic development, and international conflict; (2) to encourage and participate in similar research efforts by other organizations and individuals; and (3) to inform and learn from policy makers, activists, and the general public regarding the nature of these problems and the possible long-term strategies for mitigating them.

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CALIFORNIA WATER 2020: A SUSTAINABLE VISION

Executive Summary

California's water future depends on choices that are being made now or must be made within the next few years. It is increasingly obvious that the water policies that helped the state to become the agricultural and economic giant it is today are not up to the challenges of the 21st century. Yet those responsible for managing and protecting the state's freshwater resources continue to plan on the basis of outdated and inappropriate assumptions.

This report — the result of a year-long investigation into California's water future — presents a unique vision of a truly sustainable water future and discusses ways to realize such a vision.

The Problem

California's current water use is unsustainable.

In many areas, ground water is being used at a rate that exceeds the rate of natural replenishment. This is causing land to subside and threatening some aquifers with possible collapse. The use of ground water is almost entirely unmonitored and uncontrolled, hindering rational management. Urban water use is inefficient and poorly managed. Agricultural policies encourage the production of water-intensive, low-valued crops. Environmental water needs are poorly understood and rarely met. Fish and wildlife species are being driven toward extinction and habitats are being destroyed by withdrawal of water, as well as by development.

According to official projections, these and related problems will continue indefinitely.

The California Department of Water Resources, which produces the "California Water Plan," operates on the assumption that in the year 2020:

- California will grow the same kinds of crops, on about the same amount of land, as it does now;
- Rapidly growing urban populations will continue to waste large amounts of water on inefficient toilets and sinks, and on watering household and municipal lawns;
- Many aquifers will continue to be pumped more rapidly than they are replenished;
- Millions of acre-feet of treated wastewater will continue to be dumped into the oceans rather than being recycled and reused;
- Water needed to maintain California ecosystems and aquatic species will come and go with the rains and with human demands; and
- Droughts and floods will have ever greater effects on society and the natural environment.

In short, official projections are that water demand will exceed available supplies by several million acre feet — a gap projected in every official "California Water Plan" produced since 1957.

We believe that state water planners have been planning for a future that is increasingly unlikely and undesirable.

Traditional water planning assumes that the basic conditions affecting supply and demand will remain the same as they are today. They do not allow for the fact that social structures, values, and desires will change – as they are already changing. Even ignoring the difficulty of projecting future populations and levels of economic activities, this conventional approach to water resources planning has many limitations. Perhaps the strongest evidence of the inadequacy of this approach is the fact that it routinely produces scenarios with unsustainable conclusions, such as water demand exceeding supply and water withdrawals unconstrained by environmental or ecological limits. The costs to the state of such a future will include:

- lost industrial competitiveness and revenue;
- destroyed natural resources;
- continuing uncertainty about long-term water supplies; and
- further ill will among urban, agricultural, and environmental interests.

These costs can be avoided. Trend is not destiny, and official projections are not inevitable outcomes. It is time to develop new tools and approaches to California's water problems.

California Water 2020: A Sustainable Vision

A prosperous, healthy California is possible by 2020, with enough water for urban dwellers, a vibrant farm sector, and a robust environment. Without severely impacting any particular sector, groundwater overdraft can be eliminated, urban and agricultural water use can be made more efficient and productive, and California's natural ecosystems can be protected and restored. Figure ES-1 compares the state's future water supply and demand as estimated in this report and as projected by the official California Water Plan. In 2020, urban water demand per person could be far lower than it is today, helping to meet the demands of nearly 50 million residents, if current population projections are accurate. Agricultural production can shift away from today's emphasis on low-valued, water-intensive crops, increasing farm revenue while decreasing farm water needs. Groundwater overdraft can be completely eliminated. And the environment can benefit from more comprehensive and flexible water management.

This sustainable vision for the year 2020 would produce a more stable business environment, reduce uncertainty over water supplies, and increase the state's economic vitality and competitiveness. At the same time, the process of planning and managing the state's water resources can be made more democratic and open, bringing in whole segments of the population that have not previously been included.

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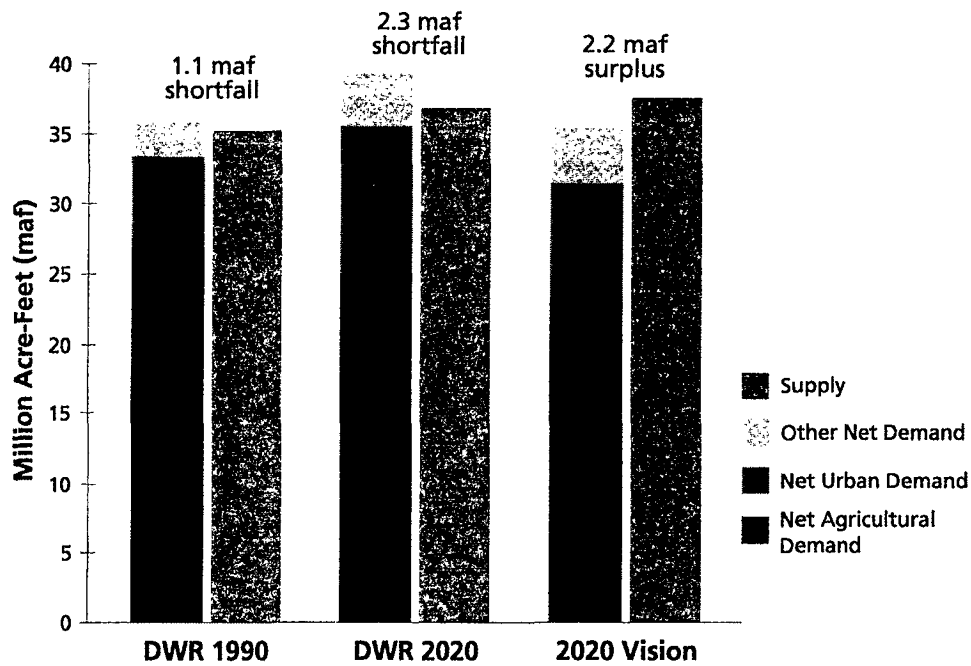
Figure ES-1
Comparison of Water Supply and Demand:
DWR 1990, DWR 2020, and 2020 Vision



Source: See Table 23.

What is Sustainable Water Use?

There has been plenty of rhetoric recently around the terms "sustainability" and "sustainable development." What is sustainability in the context of freshwater resources and why do we use the term here?

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."*

California's water resources should be managed so that today's human and environmental needs are met and so that the resource base is maintained for the future. Current water management practices are *unsustainable* because they produce groundwater overdraft, water-supply contamination by chemicals, loss of aquatic species and unique habitats, and other problems that directly diminish the state's natural resources. *To continue these practices is to squander an inherited fortune, leaving nothing for our children.*

Is sustainability a scientific concept? Not exactly. It is a social goal, much like equity, liberty, or justice. It implies an ethic. Public value judgments must be made about which needs and wants should be satisfied today — and what changes must be made to ensure a legacy for the future.

In this study we present a set of sustainability criteria for water. They were developed over the past year in discussions among people with a wide range of interests, and they embody these value judgments: that humans and natural environments should have access to the minimum amount of water necessary for survival, that the renewable characteristics of water resources should not be impaired, and that the process of water planning and management should be democratic, fair, and open.

An ethic of sustainability will require a fundamental change in how we think about water. Rather than trying to find the water to meet some projection of future desires, we must plan to meet present and future human and ecological needs with water that is available. This is an essential change in thinking, and it will require consideration at the highest levels. Such a shift does not mean we must diminish our quality of life. On the contrary, by securing a sustainable future, a prosperous, healthy California is possible by 2020.

How Do We Get There?

To realize this positive vision *no significant new supply infrastructures need be built, nor are any drastic advances in technology necessary. No "heroic" or extraordinary actions are required of any individual or sector.* The changes necessary to achieve a sustainable water future for California can be brought about by encouraging and guiding positive trends that are already under way. They can be accomplished by applying technological innovations gradually and incrementally at this time of continuing evolution in personal values and culture. These are already common characteristics of California society.

California's water policies can and must be substantially reshaped over the next quarter-century. In many cases the job has already begun and we need only nurture existing trends. Providing safe, clean water in the arid West has always required financial, institutional, and human investments, and some agencies, individuals, and organizations are likely to resist the short-term costs of any new approaches. It is imperative, therefore, that the long-term costs of *not* taking these actions — measured by the costs of new infrastructure construction, adverse impacts on human and environmental health, and the political costs of endless social conflict over water — also be brought into the equation.

A sustainable future *can* be achieved. Whether it *will* be achieved depends on the public and their elected officials.

Major Conclusions

California's current water use is unsustainable. Current water planning fails to address the water problems of the 21st century.

Continuing down the current path will lead to worsening social, economic, and environmental conflicts over water.

- Current policies reduce future flexibility and increase the risk of economic instability due to disruptions in water supply;
- Current policies produce uncertainty and a risk of future unreliability during periods of drought and shortage;
- Traditional planning leads to a large gap between water supply and expected demand, encouraging construction of new supply infrastructure.

California can achieve a more sustainable pattern of water use by 2020 without severe negative impacts on any particular sector.

The urban sector can become far more efficient and save millions of acre-feet of water.

- Average residential water use in 2020 could be 46 percent lower than the current 137 gallons per person per day, using only existing technology;
- Use of reclaimed water can increase from 0.4 million acre feet in the mid-1990s to 2 million acre-feet in 2020 and satisfy many urban demands;
- Industrial water-use efficiency could increase 20 percent over today's efficiency.

Modest re-organization of California's agricultural sector can save millions of acre-feet of water.

- The agricultural sector can be more efficient, with lower total water demand and higher agricultural revenues.
- Groundwater overdraft can be eliminated with modest changes in cropping patterns.
- By 2020, with modest shifts in cropping patterns, agricultural net water demand could decline by 3.5 million acre-feet while farm income rises by $1.5 billion (1988 dollars).

Innovative water management is necessary to protect California's natural resources.

- By 2020, more than 2 million acre-feet of water can be reallocated from urban and agricultural uses to a wide range of environmental needs.
- High mountain streams can be restored to drinkable conditions.
- Innovative agricultural policies can actually support both food production and wildlife habitat.

A major effort is needed to improve our understanding of water supply and use. Major gaps in water data make it difficult to develop and implement rational water plans.

- No one knows for sure how much ground water is used, by whom, and for what. This particular lack of data hampers efforts to control overdraft and impedes the development of rational statewide water planning.
- Residential, commercial, industrial, and municipal data on water use are spotty, at best. A comprehensive statewide water-use survey is needed.
- On-farm water use is rarely measured directly. Statewide data are needed on how much water is actually applied, evaporated from crops, returned to groundwater, and so on, as a function of crop, irrigation method, climate, and soil type.
- The water requirements for restoring and maintaining different ecosystems are poorly understood. This complicates attempts at rational joint management of water for farms, cities, and environmental needs. More information is needed on flow, timing, and water quality requirements.

Major Recommendations

The final section of the report offers a wide range of recommendations for improving California's long-term water policy and planning. Among the most important are to:

Expand efforts to promote the use of water-efficient technologies and practices.

- Current federal and state water efficiency programs should be implemented and expanded.
- Comprehensive agricultural, residential, industrial, commercial, and institutional efficiency programs are needed. These programs can include regulatory, economic, and educational components.
- Water rates for all sectors should be designed to encourage efficient water use.

Eliminate pricing policies that subsidize inefficient use of water at taxpayer expense.

- Gradually reduce, then eliminate, most federal and state water subsidies.
- Gradually reduce, then eliminate Federal crop subsidies for growing low-value, water-intensive crops.
- Adjust urban and agricultural water rates to reflect the cost of service, including non-market costs.

End the non-renewable use of groundwater in California.

- The state should establish a comprehensive groundwater monitoring program and database with open access.
- Implement institutional mechanisms for managing groundwater use at the local level in accordance with standards set by the state.

Reorganize California water-planning institutions to prepare for the 21st century.

- Make California water planning more equitable and democratic by bringing in groups that have been excluded from the process.
- Separate statewide water planning and data activities from current water project operations.
- Create an independent planning organization by streamlining existing water planning groups.

Environmental water needs should be better understood and met.

- Identify and preserve critical wetlands, together with the water supply needed to maintain them. Restore degraded wetlands.
- Set water flow and quality standards on a flexible seasonal basis, to be regularly reviewed.
- Monitor biological resources in a comprehensive, ongoing process.
- Honor state and federal agreements to protect the Bay-Delta region and California's Wild and Scenic Rivers.
- Allocate water to protect and restore native anadromous fish runs.
- Pursue the integrated management of agriculture and seasonal wetlands.

Support water transfers that improve water efficiency, enhance California's natural environment, and promote the overall well being of rural communities.

- Develop fair standards for water transfers that do not harm the environment or rural communities.
- Establish a fund, supported by fees on water transfers, to mitigate adverse impacts of transfers on rural economies, communities, and the environment.

Encourage the far greater use of reclaimed water in California through economic and regulatory incentives.

Create a statewide system of water data monitoring and exchange.

- Water data must be much more widely collected and distributed.
- Create an organization that collects, maintains, and freely distributes state water resources data.

Lifeline water allocations and rates should be implemented for the residential sector.

Integrate land-use planning and water-use planning.

- All new urban developments must demonstrate a secure, permanent supply of water before permits are approved.
- Protection of prime agricultural land and the water required to support these lands should be studied.

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.

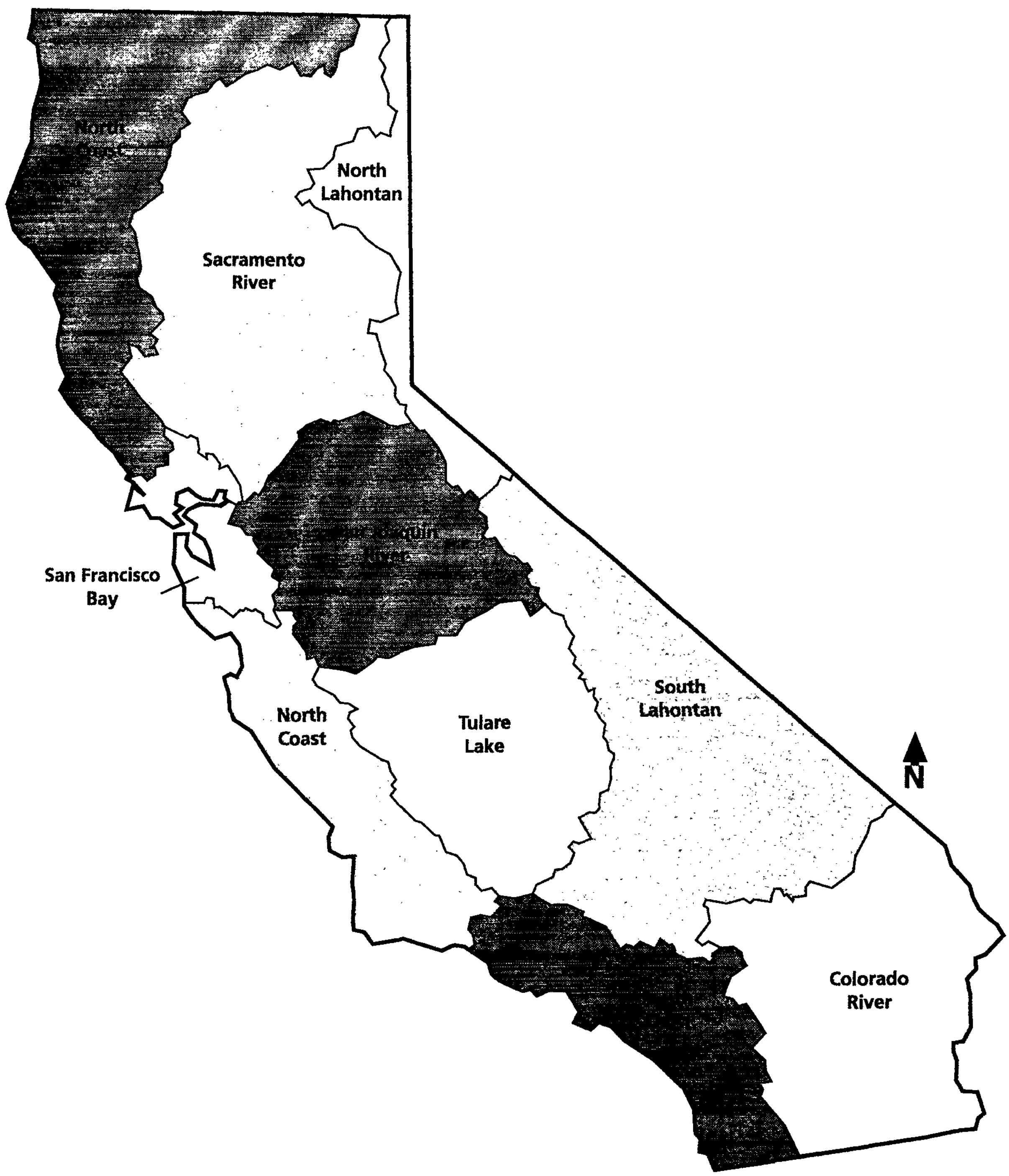
What will drive the changes we envision? Many economic, political, and cultural forces are at work in society changing our lifestyles, technologies, and institutions. These forces will continue. To reach this positive vision, we do not assume here any significant new supply infrastructures will be built, 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.

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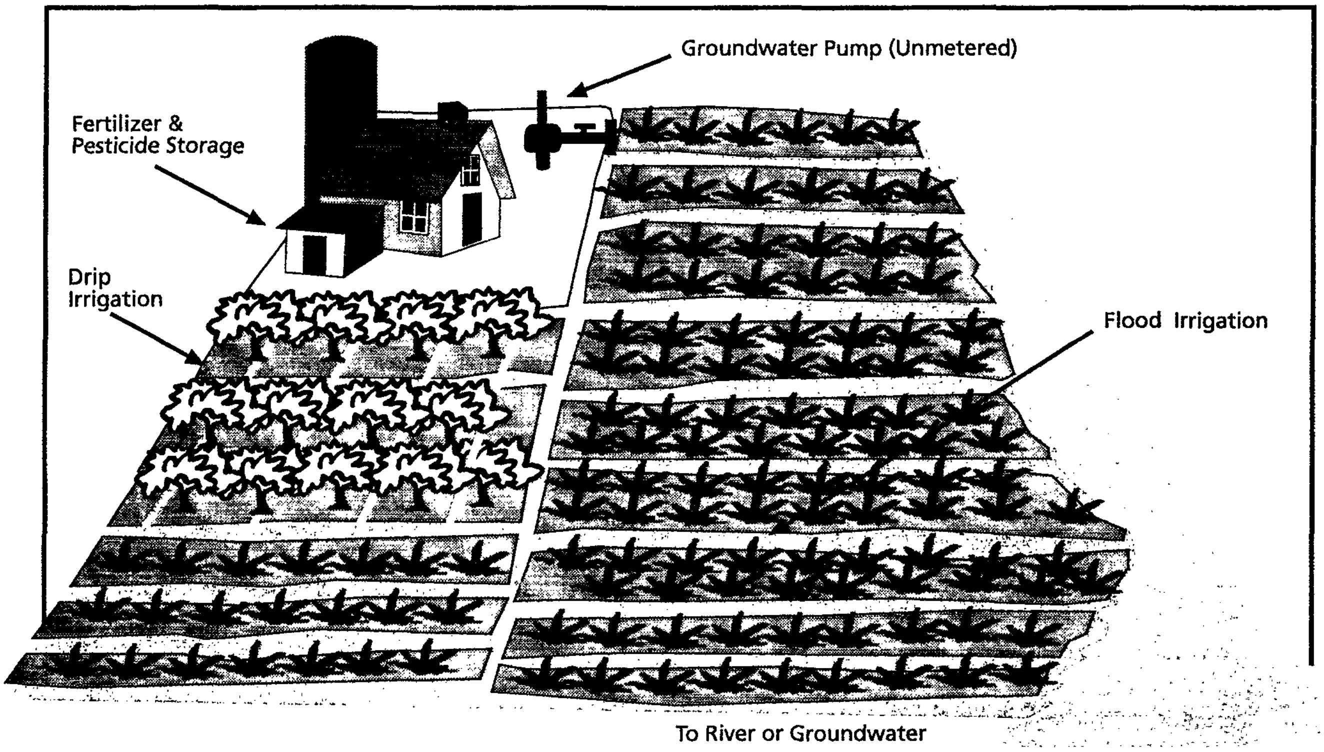

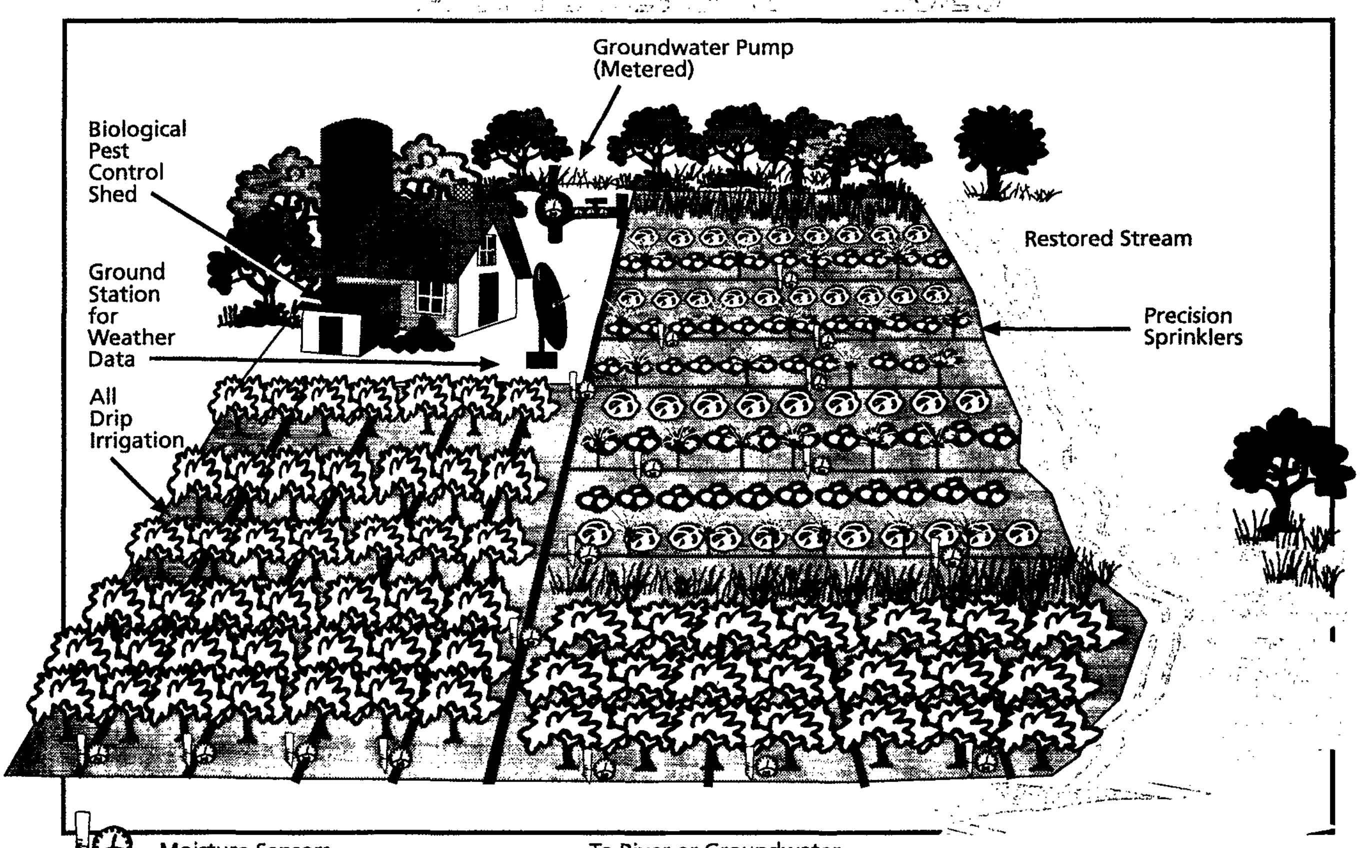

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Jane Montrose, her brother Tim, and their families own a 700-acre farm in the San Joaquin Valley north of Fresno. They grow Chardonnay grapes, almonds, gene-altered tomatoes, and peaches, with techniques and practices unknown to their parents who grew 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
[illegible]

	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.

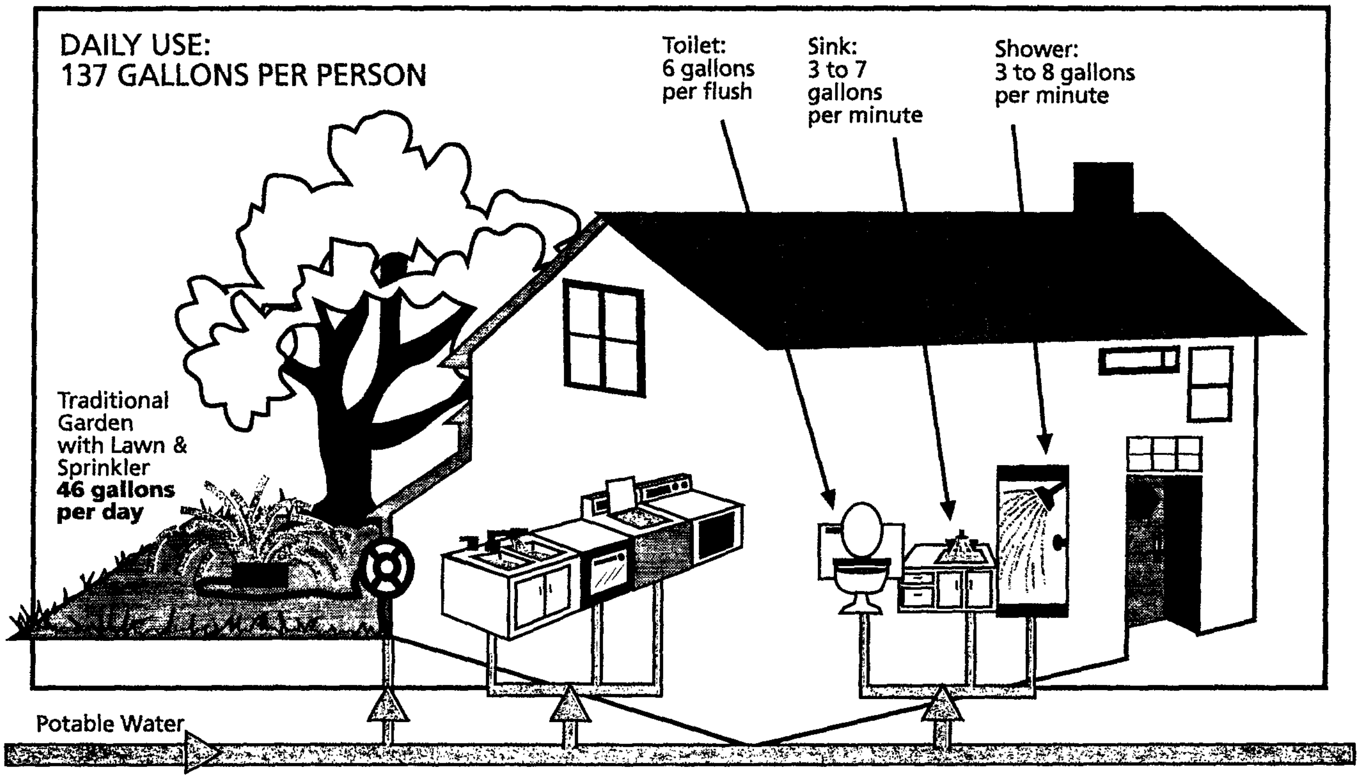
Most of the older water-using infrastructure has been replaced in residential, commercial, and municipal buildings, encouraged by state and federal policies, new standards for construction, and by water utility programs promoting replacement of fixtures in older buildings. All water fixtures meet or 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.

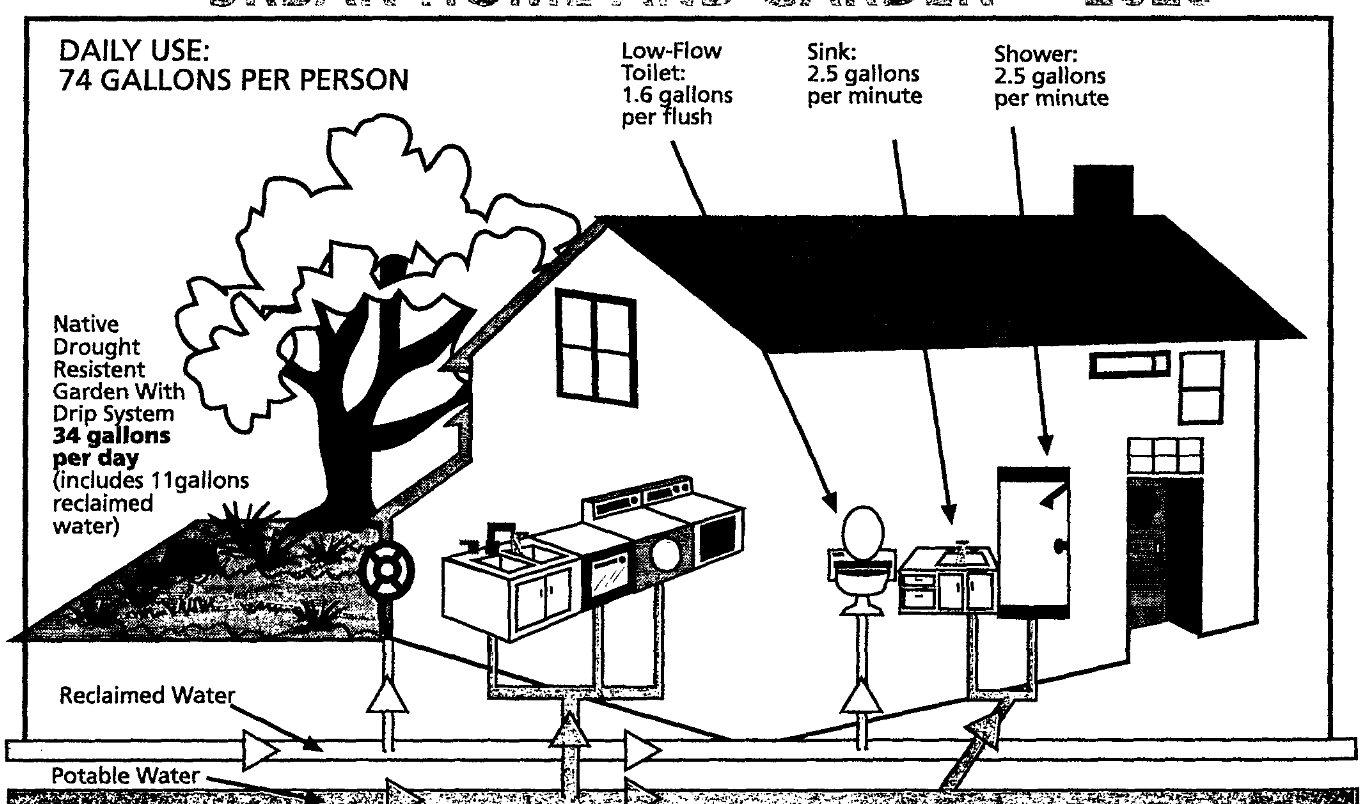
Beginning in the late 1990s, a concerted effort was started to build the infrastructure necessary to eliminate the discharge of treated wastewater into the ocean. Reclaimed water is now used for a wide range of industrial, agricultural, and commercial purposes, and meets strict health and safety standards. 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



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.

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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

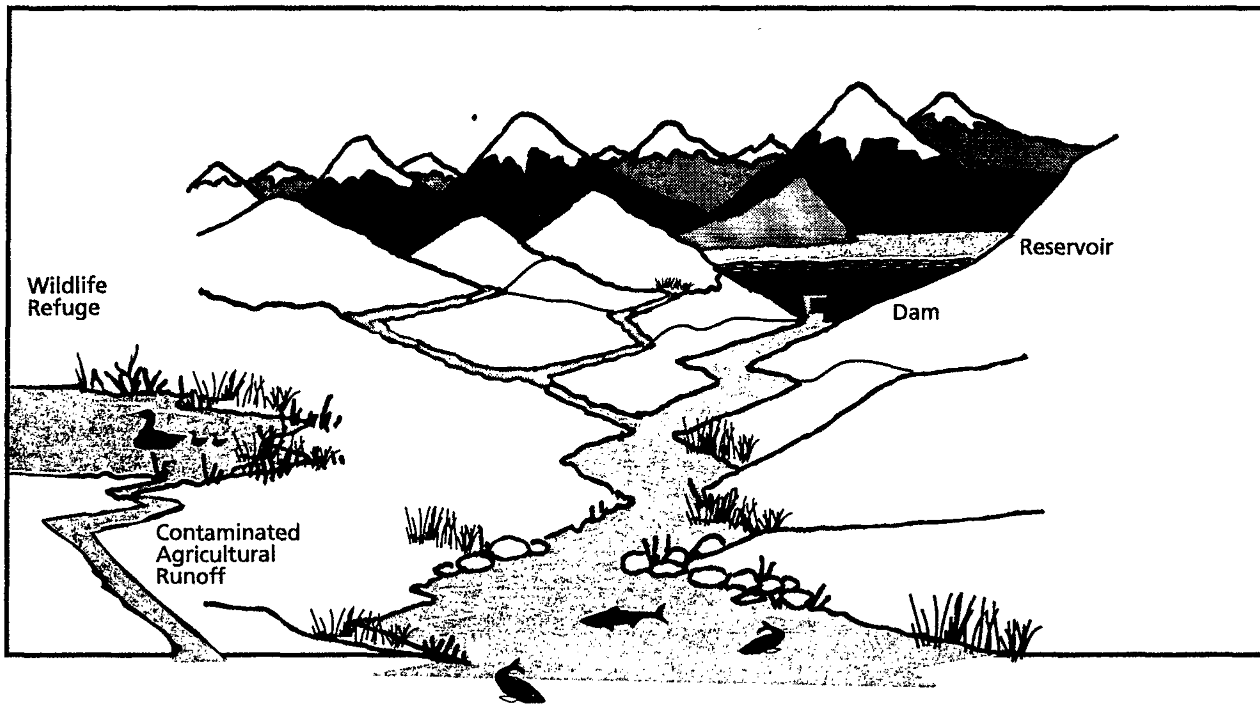
Beginning after the turn of the century, an all-out effort was made to put into place an effective and inexpensive system for collecting, evaluating, and archiving California water-resources data. In large part, this effort was stimulated by the realization that inadequate information on state water 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.

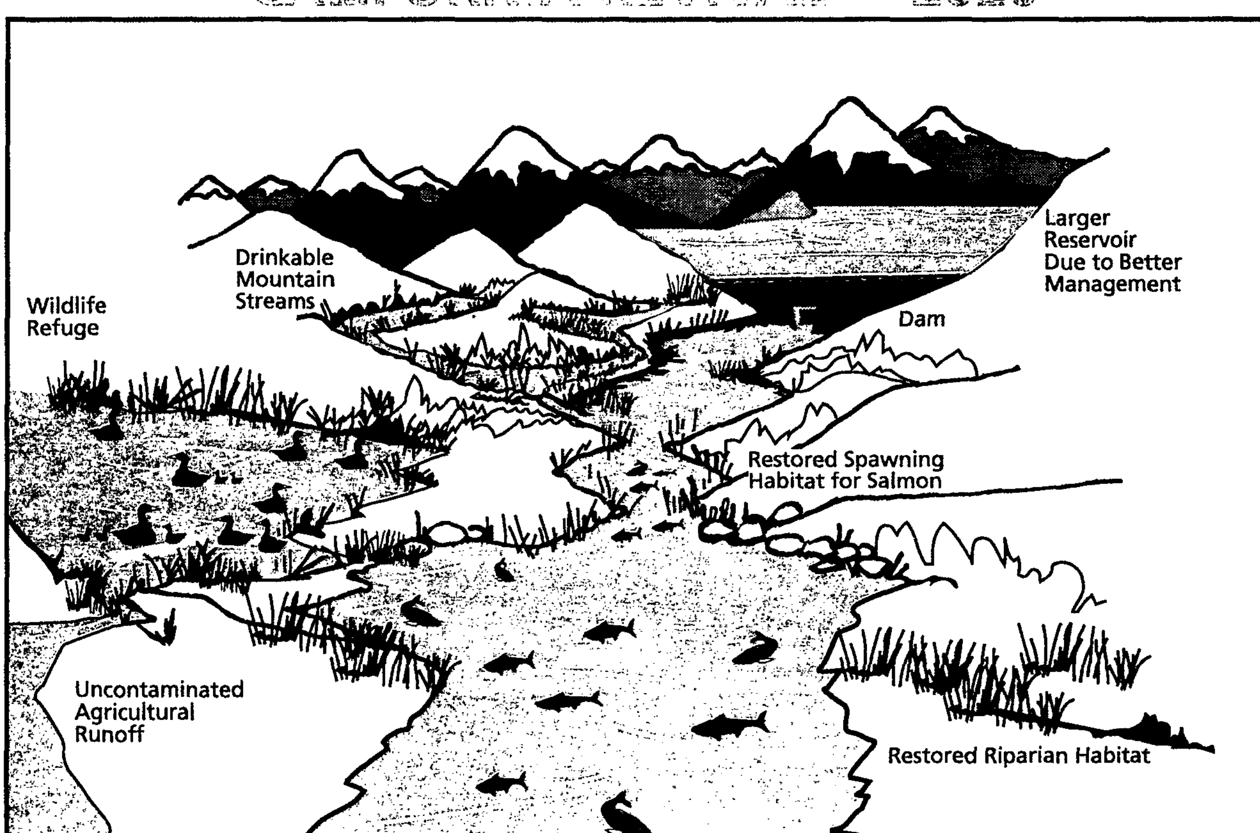
F. INSTITUTIONAL RE-ORGANIZATION

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

CALIFORNIA [illegible] - 1996



CALIFORNIA REVIVAL - 2020



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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

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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.

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 non-structural 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.

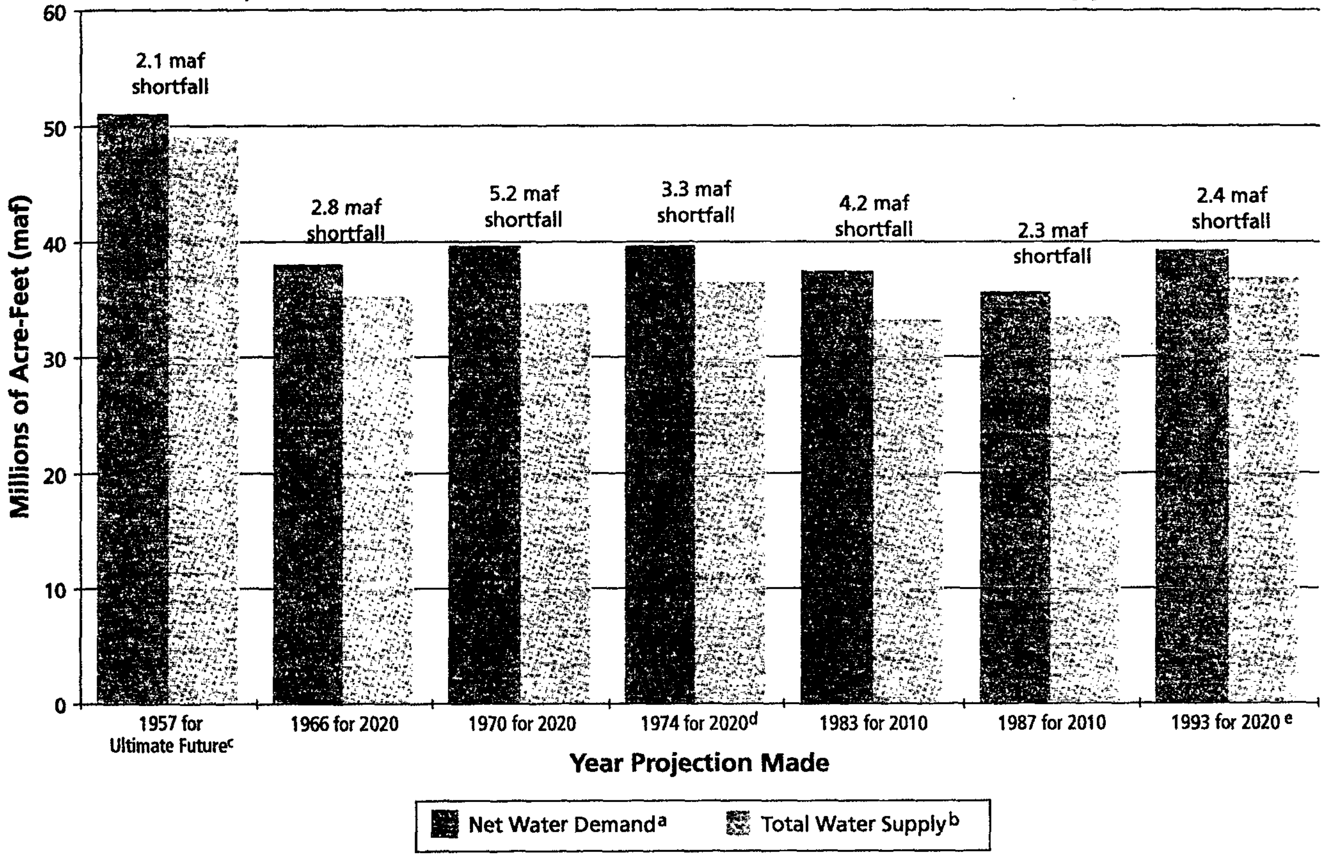
C. TWENTY-FIRST CENTURY WATER PLANNING: THE NEED FOR A NEW VISION

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.

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

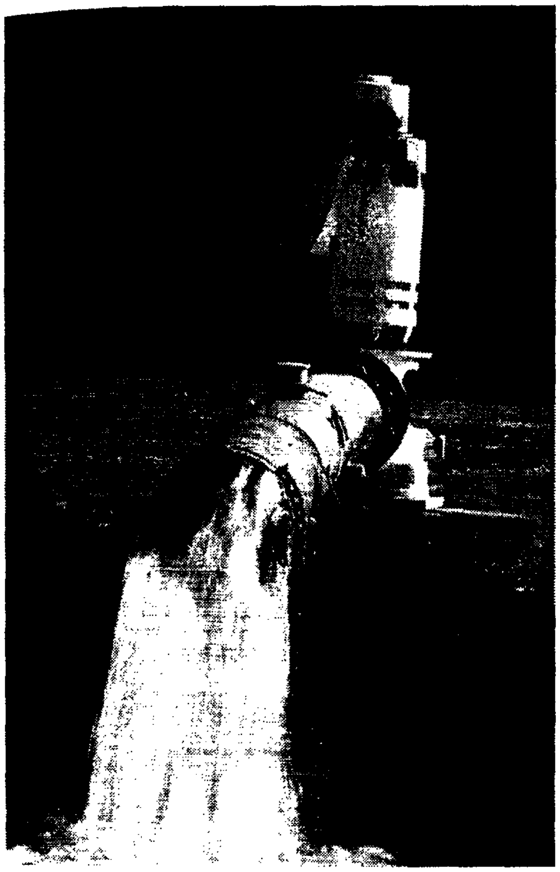
Different uses require water of differing qualities. As a result, water-quality standards for different purposes must be developed, and water quality must be monitored and maintained to meet these standards. Most of California's water is protected from contamination by federal and state regulations. 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

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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.

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 multipurpose 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).

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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 5
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 • Urban, suburban, and industrial • Miscellaneous	• Agricultural • Urban • Fish, Wildlife, and Recreation	• Agricultural • Urban • Power Plant Cooling	• Agricultural • Urban • Fish, Wildlife, and Recreation	• Agricultural • Urban • Wildlife and Recreation • Energy Production	• Agricultural • Urban • Environmental • Energy Production	• Agricultural • Urban • Environmental • 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. • Water "deficiency" in certain areas. • Groundwater overdraft in certain areas.	• Continued growth in population, industry, and irrigated agriculture. • Flood problems increasing and may need flood control dams. • Groundwater overdraft and water quality problems in some agricultural areas.	• Sufficient developed water, but conveyance facilities needed. • Resistance to and litigation over new construction projects. • Continuing growth in population and irrigated acreage. • New demands for cooling water.	• New stringent water quality goals and Wild and Scenic Rivers program. • Groundwater overdraft will worsen in San Joaquin Valley until surplus Sacramento water delivered. • Drought years could cause difficulty. • 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. • Continued population growth will require looking at all forms of water management. • Overdraft continues. • Leveling off of irrigation water use.	• Water supply is sufficient in 3 out of every 4 years. • In dry years, reservoirs and groundwater are drawn upon, and conservation and perhaps rationing are required.	• Six year drought from 1987 to 1992. • CVPIA (1992) and other actions taken to protect environment. • During drought, present supplies insufficient to meet demands. • 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.

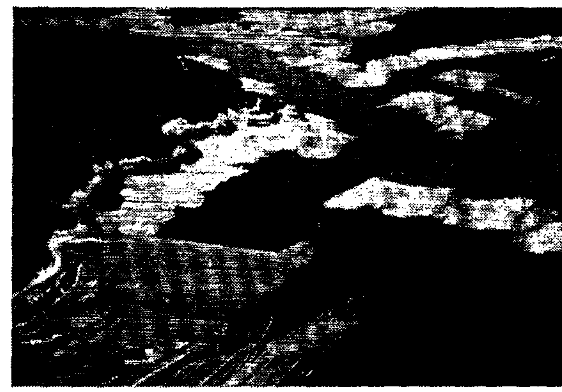
Despite this consideration of demand management, the basic approach taken by the DWR in the latest Plan Update remains largely the same as in the past, and the projected "gap" between demand and supply in the year 2020 remains large. Projections of future demand are still made without supply constraints, 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.

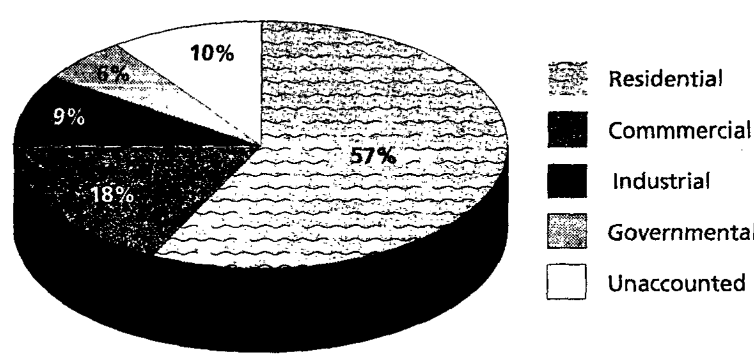


Major artificial reservoirs, such as Clair Engle, are heavily drawn down during droughts. (Courtesy of DWR.)

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.

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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

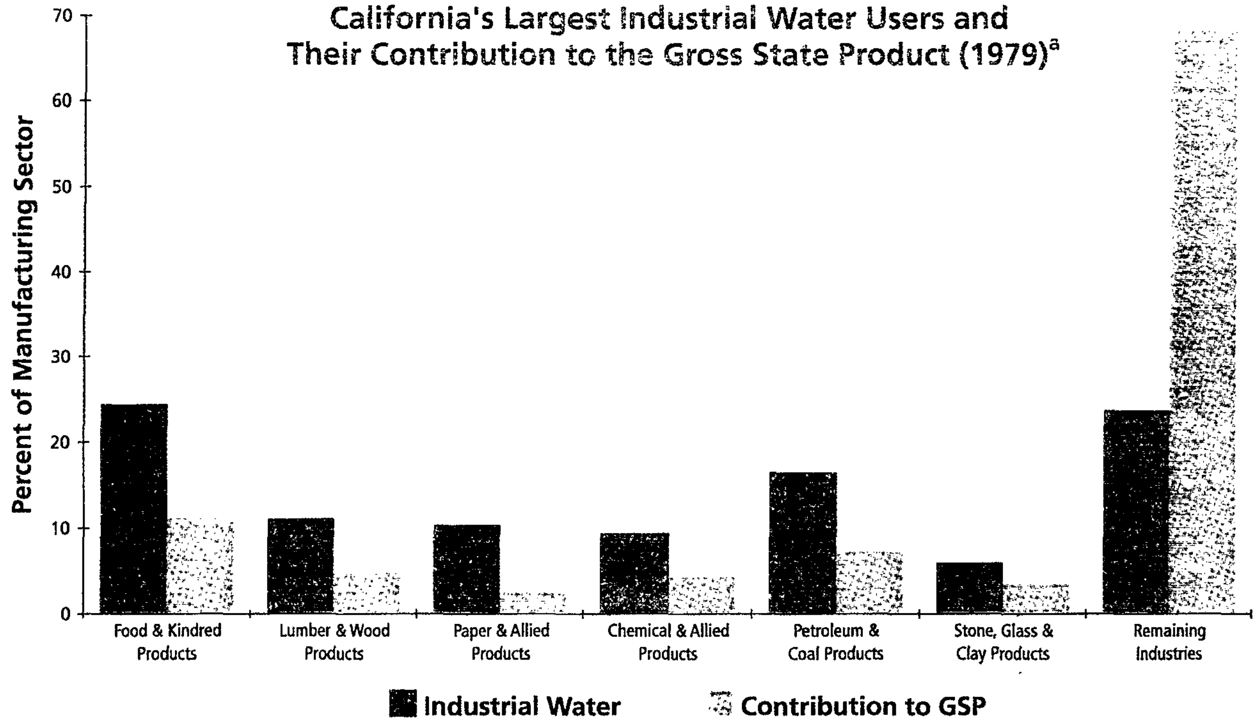
Producing the goods we use in our everyday life – from clothes and computers to food products, paper, plastics, and televisions – requires large amounts of water. Producing one ton of paper with commonly used practices can consume as much as 700 tons of water. Making a ton of steel can take 280 tons 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

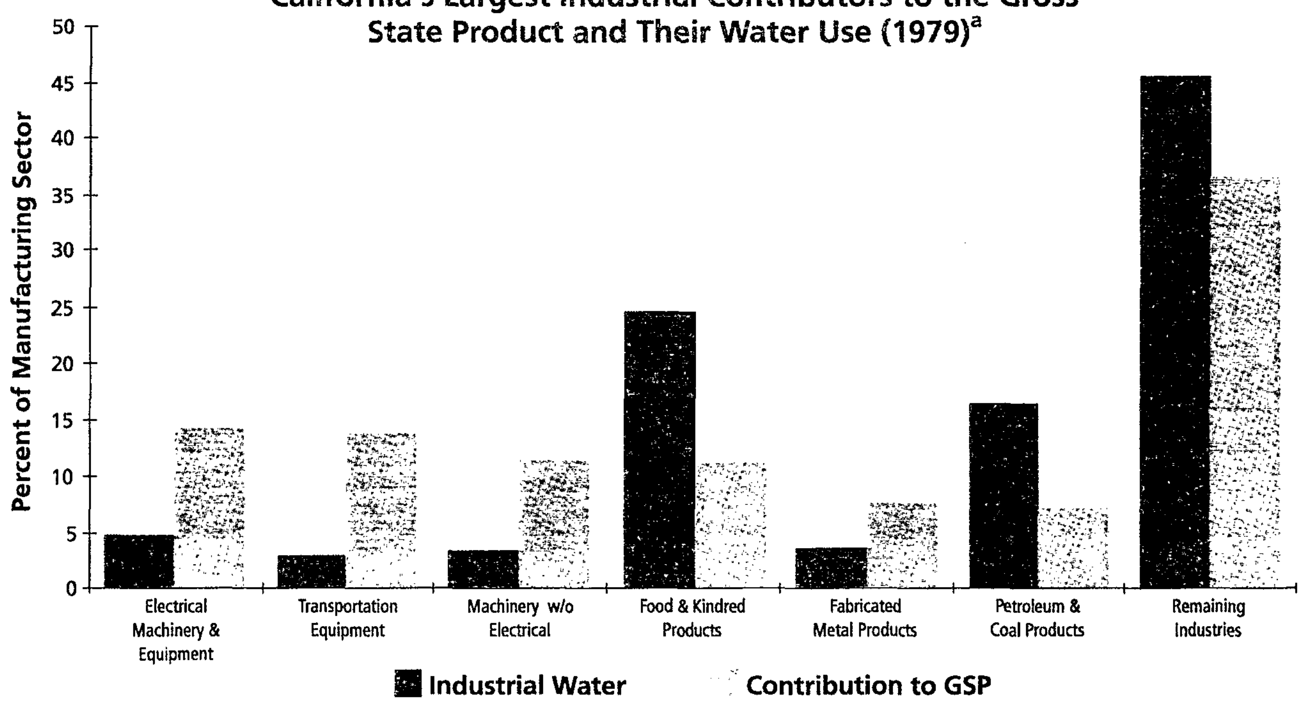
[8] A study of southern California water agencies found that 28 percent of total residential water use was seasonal (i.e., those uses that vary from month to month in response to weather conditions) (Dziegielewski et al.1990, 1991).

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 [illegible]

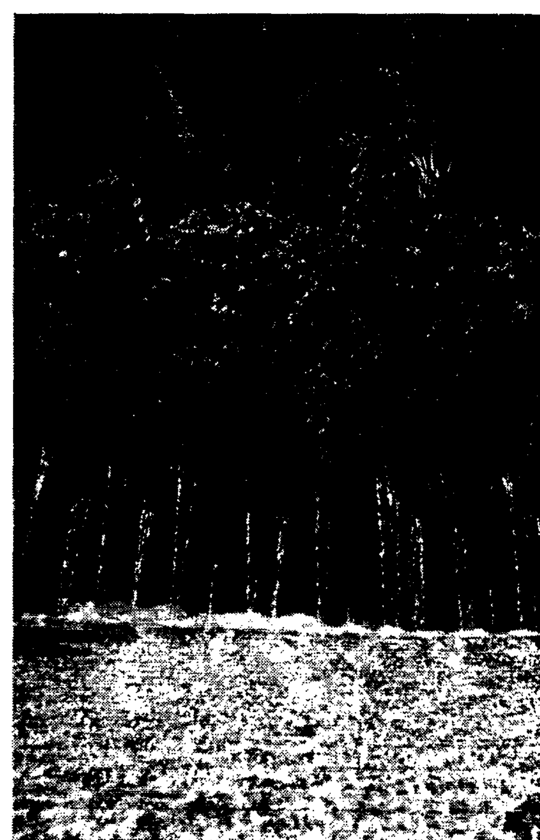
[illegible] Commercial Applied Water Use, by Hydrologic Region

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.)

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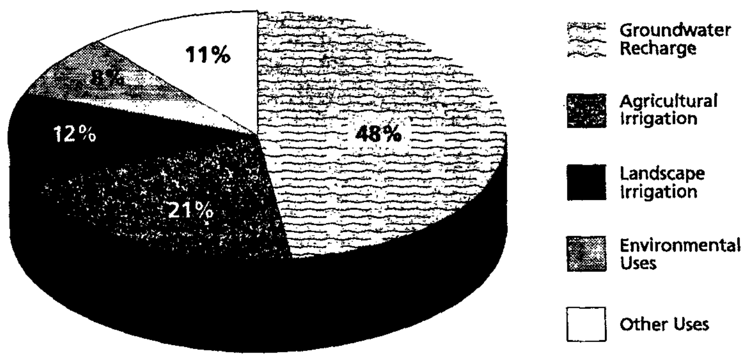
according to a 1993 WateReuse Association of California report, 48 percent of the reclaimed water being used goes to recharge groundwater aquifers. Twenty-one percent of the reclaimed water is used for agricultural irrigation and 12 percent for landscape irrigation. The environmental sector, despite 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.

[illegible]
Irrigated Acreage of Selected Crops for [illegible]

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.

[illegible]
Total Irrigated Crop Acreage, [illegible]

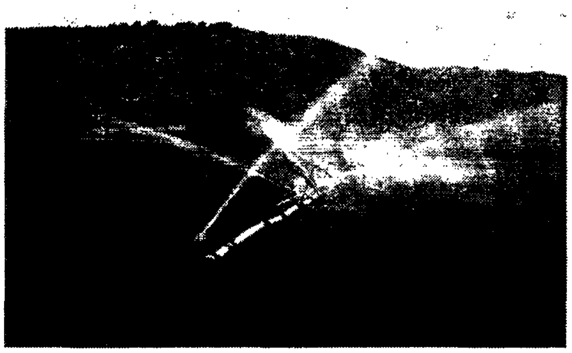
Irrigated Crop	Thousand Acres 1960	Thousand Acres 1980	Thousand Acres 1990	Percent Change 1960 to 1990	Percent Change 1980 to 1990
Grain	1,067	1,485	988	-7.4	-33.5
Rice	374	545	517	38.1	-5.1
Cotton	812	1,545	1,244	53.2	-19.5
Sugar Beets	170	210	216	27.3	2.9
Corn	with other field	442	403	N/A	-8.8
Other 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).

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.

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.)

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.

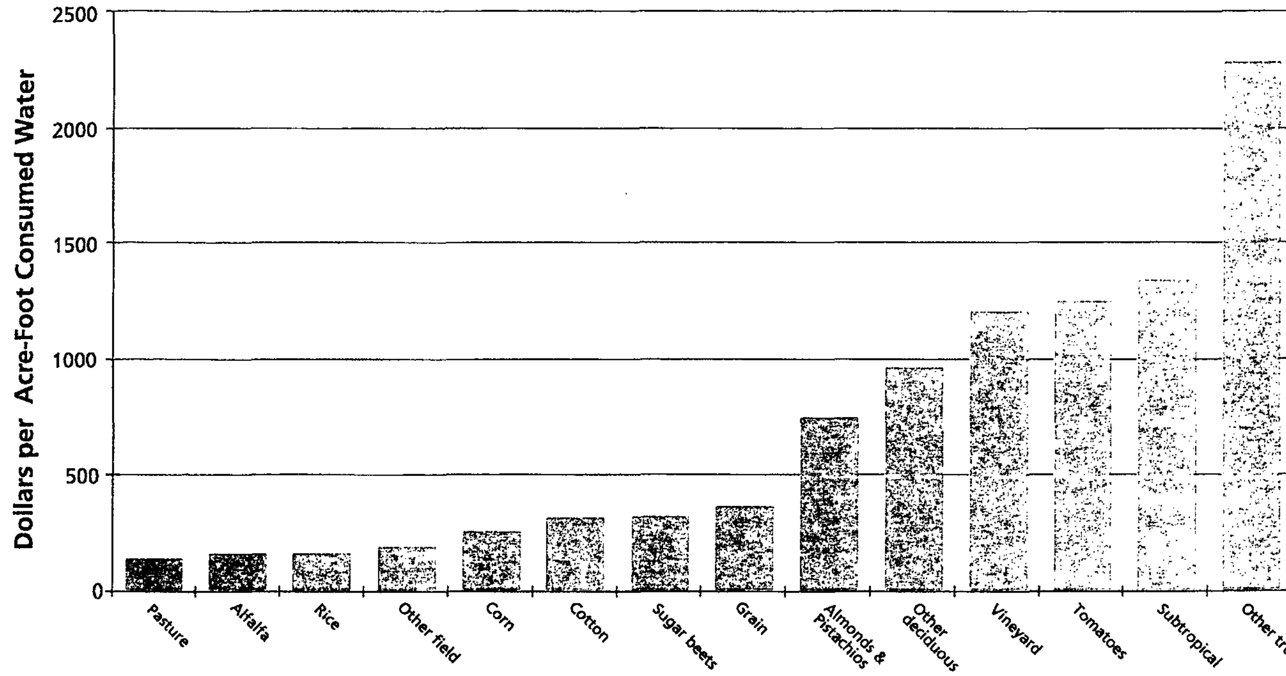
These disparities lead to enormous differences in water productivity. (Sunding et al. 1994) have estimated that the least productive 20 percent of irrigation water in terms of farm value produced less than five percent of total agricultural revenues. Most of this water goes to produce alfalfa hay and 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

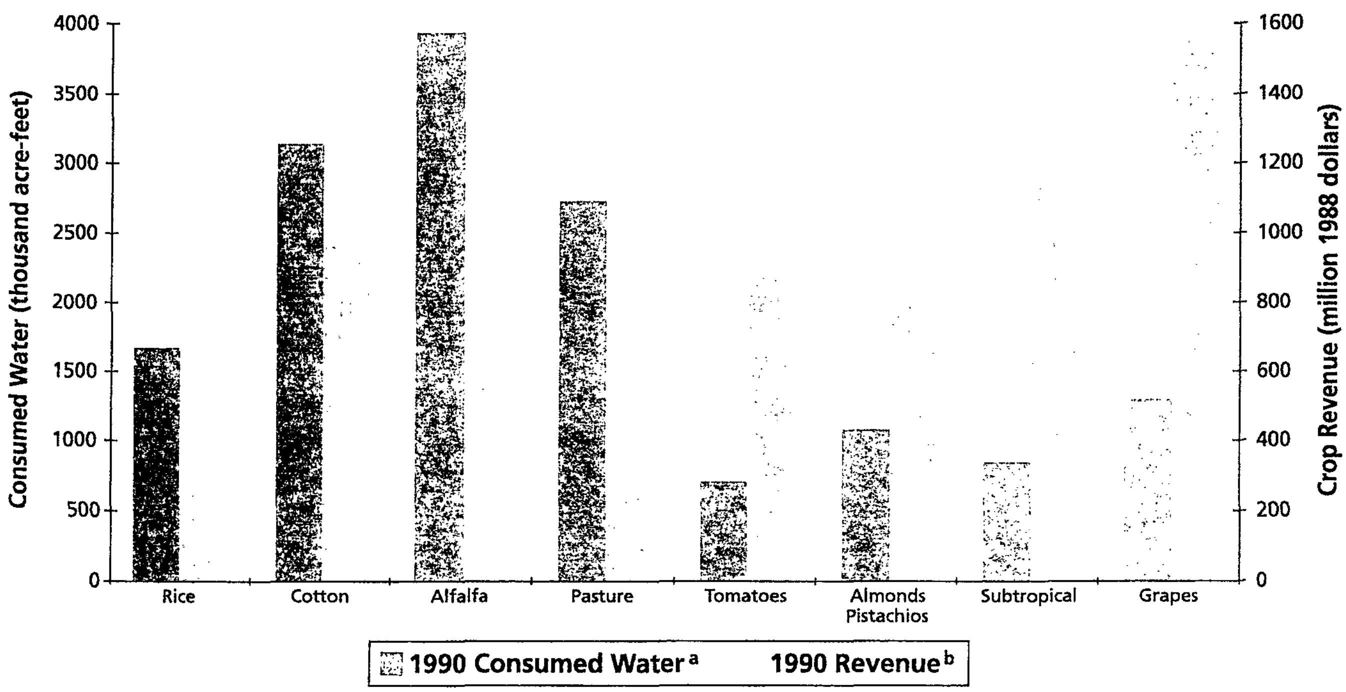
Revenue Per Acre-Foot of Consumed Irrigation Water [illegible]



Sources: DWR 1994a and Zilberman et al.

Figure 9

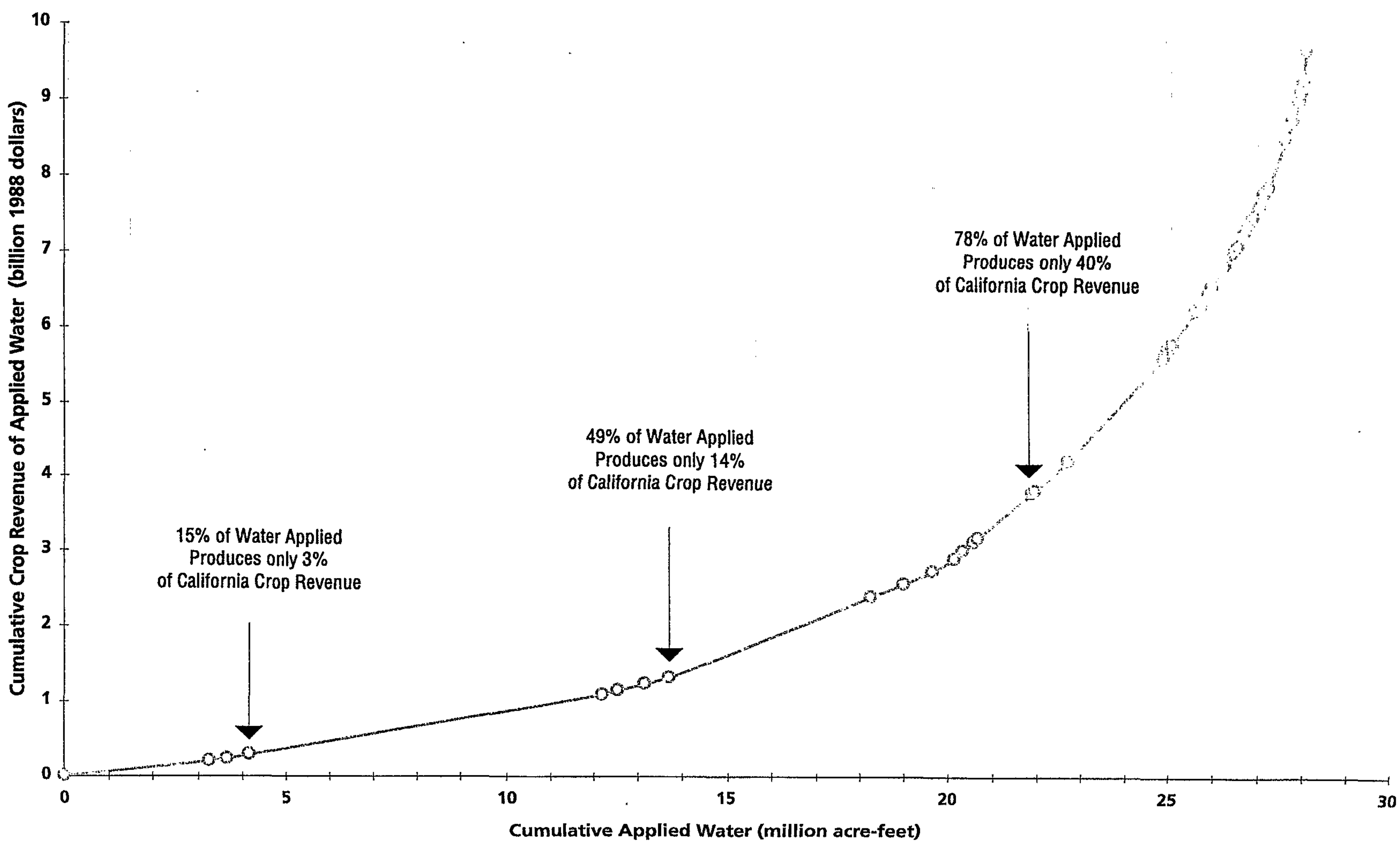
1990 Consumed Water and Crop Revenue for Selected Crops



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

Figure 1[illegible]

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

[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.

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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

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

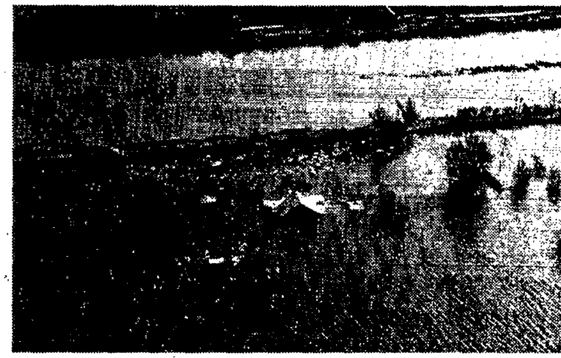
There is growing concern among climatologists and meteorologists that the world is beginning to experience increasingly severe weather patterns. Floods and droughts — a natural consequence of climatic variability — have occurred since the beginning of time, as chronicled in the book of Genesis, in the 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.

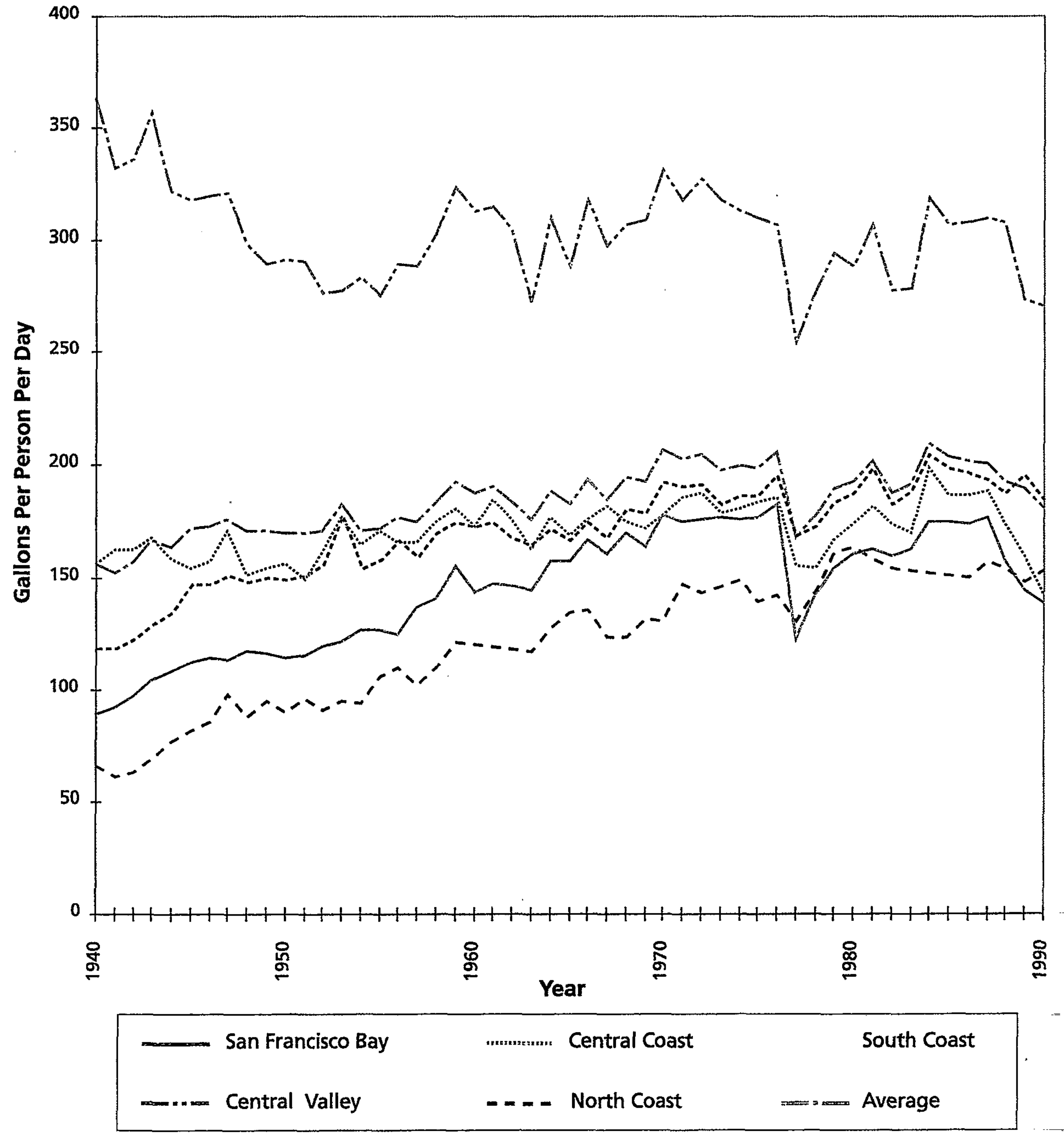
The drought of 1976 and 1977 was the most severe two-year drought in the past century. This drought not only revealed the vulnerability of the state's large reservoirs to persistent water shortages, but was a turning point for urban water policy. For the first time, urban water use became the subject 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.

[illegible]

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."

Where Do We Want To Be: California Water 2020

As long as we continue to mismanage our water resources, the gap between water demand and supply will continue to widen, exacerbating groundwater overdraft, surface water disputes, and water quality problems. We have the opportunity, tools, and ability to create a remarkably different urban and agricultural economy, one that can restore ecosystems and protect the environment while bringing forth innovation, equitable use of resources, meaningful work, and economic security. The vision presented at the beginning of this report offers a positive goal for California water planning and management. This section offers the analytical and technical background to support the goals identified in that vision. These goals meet the sustainability criteria developed earlier. How they might be achieved is discussed in the final section.

A. SUSTAINABLE URBAN WATER USE

The past approach of expanding urban water supplies by tapping ever more distant sources to meet presumed future demands is no longer appropriate in California. Increasingly, water managers must try to determine how to satisfy human needs and desires for water within the limits of the resources that are presently available.

What do humans need? According to health officials worldwide, the minimum amount of water a person "needs" for a healthy living standard is about 20 gallons per day (WHO 1971, NAS 1977). This benchmark includes sufficient water to provide adequate sanitation services, maintain human health, and prepare food. Water required to grow or produce food is not included, nor are typical municipal, commercial, and industrial water uses. Any domestic water use that exceeds that level, whether in support of people's livelihood or their lifestyles reflects personal, economic, and social choices, and patterns of urban living.

To satisfy the minimum water requirement described above, California in the year 2020 will require about 1.1 maf (less than 25 percent of the 1990 residential demand). Official projections based on conventional analysis for 2020 are that Californians will still use over 100 gallons per person per day more than this minimum.

Because the water required to meet basic human needs comprises a relatively small amount of total residential water use, meeting the minimum water requirement to maintain human health is not a serious challenge. By providing this minimum level of water for human consumption at lifeline rates, California will assure that the basic water needs of its citizens are met. Water use beyond the minimum water requirement should be guided by efficiency and equity considerations, as well as other measures to ensure that the renewability and quality of our water supply are maintained.

We have the opportunity, tools, and ability to create a remarkably different urban and agricultural economy, one that can restore ecosystems and protect the environment while bringing forth innovation, equitable use of resources, meaningful work, and economic security.

1. Residential Water Use

Permanent residential water savings by 2020 will come from improvements in both indoor and outdoor water-use efficiency and from conservation management practices. Indoor water savings will principally result from installing water-efficient fixtures in new and existing dwellings to meet existing standards. Smaller, yet substantial, savings will also be achieved through changing water-use practices (i.e., taking shorter showers, not running the faucet while shaving or brushing, and so on), but we do not include these behavioral changes in our estimates. Outdoor water savings will principally result from improving irrigation efficiency, reducing turf size, xeriscaping, and using reclaimed water for outdoor irrigation. Through improvements in indoor and outdoor

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water use, per-capita residential applied water use in 2020 will be less than 75 gallons per person per day, a more than 45 percent decrease from the 1990 per-capita water use level (see Table 3).

a) Residential Indoor Water Use

The greatest long-term, permanent indoor water savings will come from installing water-efficient fixtures in new construction and replacing conventional fixtures in existing residences, businesses, and industry. In recent years, in part due to the recent droughts, many new efficient appliances and fixtures have become available. Their sale is now mandated by the 1992 National Energy Policy Act's water-efficiency standards, which should have an enormous impact on urban water demand over the next 25 years.

Existing non-ULF (ultra-low-flow) toilets, faucets, and showerheads can be replaced with ULF toilets, water-efficient faucets, and showerheads when they break down or when houses are remodeled. Studies have commonly used natural turnover rates in the range of three to seven percent per year for toilets (California Urban Water Conservation Council 1992). Since the cost of toilets is substantially higher it is not unreasonable to assume the same turnover rates for faucets and showerheads. Using five percent as a conservative but realistic estimate of the natural turnover rate of residential water fixtures, over three-fourths of all Californians will live in homes that meet or exceed the water-efficiency standards of the NEPAct by 2020.

According to a number of studies, the NEPAct standards have the potential to reduce residential water use for toilets, showerheads, and faucets by 62 percent for fixtures installed prior to 1980 and 39 percent for fixtures installed between 1980 and 1992 (Vickers 1991, Vickers 1993). Results of the Institute's analysis, as illustrated in Table 14, suggest that the NEPAct water-efficiency standards will substantially reduce residential indoor applied water use in California by the year 2020 compared to conventional estimates of future urban demand.

If three-quarters of all indoor residential water-using fixtures (toilets, showerheads, and faucets) in California meet the NEPAct standards by 2020, total indoor residential water use will increase slightly from 3.1 maf in 1990 to 3.4 maf (a 10 percent increase from 1990), despite a 63 percent increase in population. If by 2020 California was to achieve complete replacement of all inefficient toilets, showerheads, and faucets, it could actually reduce indoor applied water use by about 0.3 maf from the 1990 level or a 10 percent decrease — a substantial reduction in per-capita indoor use. Savings are even possible in communities that have been active in promoting water-efficient fixtures and appliances. For example, in 1994 about 81 percent of the single-family homes in the Marin Metropolitan Water District, which already has a low per-capita residential water use, still had toilets that use 3.5 or more gallons per flush. In multi-family homes, 87 percent had toilets that use 3.5 or more gallons per flush (Fiske and Weiner 1994).

Table 14
2020 Residential Indoor Water Use

Scenario	Total Applied Residential Indoor Water Use (million acre-feet)	Per-Capita Applied Residential Indoor Water Use (gallons per person per day)
DWR 1990 Residential Indoor Applied Water Use [a]	3.1	91
DWR 2020 Residential Indoor Applied Water Use [a]	5.0	91
Residential Indoor Applied Water Use in 2020 with 75% Compliance with the 1992 NEPAct (vision) [b]	3.4	61
Residential Indoor Applied Water Use in 2020 with 100% Compliance with the 1992 NEPAct (vision) [b]	2.8	51

[a] *The DWR total applied residential indoor water use estimates are the product of the current residential water use percentage times the fraction of indoor use times total urban water use (59% x 2/3 x total urban water use) (DWR 1994a).*

[b] *The 2020 vision estimates of total applied residential indoor water use are based on 75 and 100 percent compliance with the 1992 National Energy Policy Act.*

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Our analysis, as summarized in Table 14, does not assume improvements in the water-use efficiency of other major fixtures, such as dishwashers and washing machines. In fact, washing machines that use half the water of current models are available and improvements in technology are continuing to be made. Including these in our calculations would have reduced future residential indoor water use even more.

b) Residential Outdoor Water Use

In California, most outdoor use in the urban sector occurs during the dry summer months. Although detailed data on outdoor water use are not available, official estimates are that about 2 maf of potable water were used to water exterior landscaping in the residential, municipal, and commercial sectors in California in 1980. By 1990, urban outdoor water use had risen to over 3 maf (DWR 1994b). Using DWR's estimates, outdoor residential water use in 1990 was about 1.5 maf, with another 1.5 maf of outdoor water use divided among the other urban sectors. Under conventional projections, potable water demand for landscaping continues to increase as population grows and as development moves inland, where hotter and dryer conditions lead to higher per-capita outdoor use (DWR 1994b). By 2020, conventional trend analyses suggest that outdoor residential water use would grow by 1 maf.

This upward trend in outdoor water use need not continue. Many policies are already being explored to reduce demand for urban irrigation, including technological improvements that increase irrigation efficiency, reductions in the area of turf requiring water, replacement of lawns with native, drought-resistant plants, and replacement of potable water for turf irrigation with gray or reclaimed water. Studies have concluded that outdoor water use can easily be reduced by more than 25 percent simply by improving outdoor irrigation practices (Sunset 1987). Combining this with drought-resistant plants and substituting reclaimed water for potable water use, per-capita potable water use can be decreased by at least 50 percent.

This upward trend in outdoor water use need not continue. Many policies are already being explored to reduce demand for urban irrigation.

Reducing per-capita outdoor water use by 25 percent, achievable with the changes mentioned earlier, would result in an increase in total outdoor residential water use in the year 2020 of 350,000 af, instead of 1.0 maf, over 1990 levels. A 50 percent reduction, which would require more extensive changes, but could be accomplished with methods and technologies already available, would reduce total residential outdoor water use in 2020 to 1.3 maf, 200,000 af fewer than the amount used in 1990. These scenarios of applied outdoor water use are summarized in Table 15.

Table 15

2020 Residential Outdoor Water Use

Scenario	Total Applied Residential Outdoor Water Use (million acre-feet)	Per-Capita Applied Residential Outdoor Water Use (gallons per person perday)
DWR 1990 Residential Outdoor Applied Water Use[a]	1.5	46
DWR 2020 Residential Outdoor Applied Water Use[a]	2.5	46
2020 Residential Outdoor Applied Water Use with 25% Outdoor Savings (vision)[b]	1.9	34
2020 Residential Outdoor Applied Water Use with 50% Outdoor Savings (vision)[b]	1.3	23

[a] *The DWR total applied residential outdoor water use estimates are the product of the current residential water use percentage times the fraction of outdoor use times total urban water use (59% x 1/3 x total urban water use) (DWR 1994a).*

[b] *The 2020 vision estimates of total applied water use are based on 25 percent reductions in outdoor potable water use and 25 percent substitution of potable water use with reclaimed water.*

In summary, by 2020, as residential customers become more water conscious and reduce inefficient indoor and outdoor water uses, total residential water use could be in the range of 4.1 to 5.3 maf (compared to the 4.6 maf used in 1990 and the nearly 7.5 maf projected for 2020 by conventional approaches). Even with 100 percent compliance with the NEPAct water efficiency standards and with a 50 percent reduction in outdoor water use, per-capita residential water use will still be approximately 75 gallons per person per day. This exceeds Israel's 1990 per-capita water use of 70 gallons per person per day (Fishelson 1993). Nonetheless, it would be an enormous savings of nearly 3.5 maf per year over current California projections for 2020.

2. Non-Residential Water Use

Residential water use accounts for just under 60 percent of urban water use. The remaining urban use is divided among the commercial, industrial, and municipal sectors. Much commercial water use can be saved with technologies and policies similar to those available in the residential sector. The potential for those improvements has been documented elsewhere (Gleick, Stewart, Norman 1994).

The substantial improvements in water-use efficiency achieved by several individual industrial corporations over the past decade are also indicative of the kinds of savings possible in the industrial sector as a whole. The reuse and recycling of cooling water, for example, would considerably reduce industrial water demands for many large industries.

There is also considerable potential for changes in the structure of the industrial sector toward less water-intensive production. Many industries have already begun to explore low-cost water-efficiency projects. Plants that have already invested in conservation programs and technology would require increasingly larger investments to further reduce their water use.

Estimates of future conservation potential for the non-residential (commercial and industrial) sector are around 20 percent (EBMUD 1994). Table 16, for example, shows the conservation potential in a set of California's major industrial groups calculated by one industrial study (Wade et al. 1991). This study looked only at available conservation potential for half of California's water-using industries and did not consider the potential for substitution of reclaimed water. Nevertheless, this analysis provides background for estimates of future efficiency improvements in the industrial sector.

The Institute projects that the industrial and commercial sectors in 2020 will be both more water efficient at what they do and restructured toward less water-intensive practices. In the first case, we project that the average water-use efficiency for each component of California's industrial sector will increase by about 20 percent — the average improvement

Table 16
California Industrial Water Conservation Potential

Standard Industrial Classification Codes	Industry Group	1989 Industrial Water Use (thousand acre-feet per year)	Potential Conservation (thousand acre-feet per year)	Percent Savings (percent)
20	Food Groups	82.3	10.0	12.2
291	Refining	126.7	24.3	19.2
281	Chemicals	27.2	11.0	40.4
327	Concrete	19.1	1.8	9.4
372	Aircraft	13.6	2.1	15.4
265	Paper Boxes	12.4	3.6	29.0
357 and 367	Computers/Electronics	15.0	3.9	26.0
Miscellaneous	Other Industries	25.3	4.3	17.0
TOTALS		**321.6**	**61.0**	**19.0**

[a] *These estimates come from an incomplete survey of California industries and assume no change in technology.*

Source: Wade et al. 1991.

in water-use efficiency that could be achieved with full implementation of today's best available technologies and industrial processes. By 2020, new technologies will permit many industries to improve substantially beyond the best available in 1990, but we do not include such projections here.

In the second case, total industrial water-use efficiency is assumed to improve an additional 20 percent because of changes in the structure of the industrial sector, as opposed to improvements within each industry. Such changes are already underway. In the past two decades, several major industries that are also water intensive have become much less important to California's economy. For example, fabricated metal products, petroleum and coal products, and the primary metal sector produced one-fifth of the state's economic output in 1979. By 1990, this had dropped to less than one-tenth. These industries were responsible for 25 percent of California's industrial water use in 1979. During the same period, the manufacture of computers, electrical equipment, and scientific instruments went from generating 17 percent of state GDP to nearly 25 percent, while initially using only six percent of industrial water.

From 1980 to 1990, the combination of these changes reduced California's total industrial water use by an estimated 33 percent (DWR 1994a, 1994b). We project that an additional 40 percent drop over the next 25 years, described above, is well within the capability of the state's industries. Comparable savings may be available in other non-residential sectors.

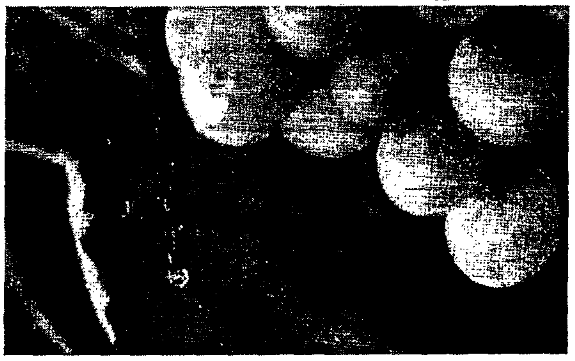
Unlike the residential sector where per-capita water use is expected to drop dramatically as a result of the NEPAct water efficiency standards, the impacts of the NEPAct non-residential water efficiency standards for fixtures and fixture fittings are less certain. They do not take effect until January 1, 1997, and they allow some exemptions for safety showers, toilets and urinals used in prisons, and other products that require unique designs and higher flow rates. Some commercial toilets are also allowed a higher water-use rate until they can be redesigned to operate reliably at lower volume. Any non-residential analysis will be further complicated by limited availability of non-residential water use data. Nonetheless, despite the uncertainty surrounding the impacts of the NEPAct on the non-residential sector, especially during the early years, by 2020 per-capita non-residential sanitary water use will be substantially less than it is today.

B. SUSTAINABLE AGRICULTURAL WATER USE

Agriculture has long played an important role in California. Much of the development of the state's water resources in the 20th century occurred with the idea that the water would be used by family farmers, thereby strengthening the nation's democracy, building the state's economy, and enhancing rural community. But despite the notable successes at producing food, the vision of a strong rural community based on small, independent, family farmers portrayed by the 1902 Reclamation Act has not been realized. Today, the challenge is to envision an agricultural sector that is vitally tied to rural livelihood and is consistent with the sustainability criteria.

There are many different ways for agricultural producers to use water to the benefit of their surrounding communities. Given enough time and information, farmers have long shown themselves to be flexible, dynamic, and innovative in response to water constraints, technological changes, and alternative agricultural policies.

Under almost any possible vision of California, the agricultural community will continue to play an important role in the future. The sustainability criteria mentioned earlier sketch only the outlines of what such a community could look like. There are many different ways for agricultural producers to use water to the benefit of their surrounding communities. Given enough time and information, farmers have long shown themselves to be flexible, dynamic, and innovative in response to water constraints, technological



Precise drip irrigation technology can reduce water applied to many crops. (Courtesy of DWR.)

changes, and alternative agricultural policies.

Farmers face various choices in water use given certain constraints and incentives. In general, farmers behave rationally, trying to maximize profits, and for them, water is merely one factor of production that affects net income. But farmers also make choices independent of profit maximization; experience, family traditions, and community values all factor into their decisions. More water use does not necessarily imply a healthier community; nor does less water use imply economic losses, as we demonstrate below. Short-term choices that affect water needs include what crops to grow, what sources of water (including ground water and surface water) to use, and how to irrigate. In the long-term, farmers are able to invest in more efficient irrigation technology, increase efficiency of on-farm delivery systems, install more groundwater pumping capacity or on-farm surface storage, permanently retire land, or leave farming altogether. All these long-term decisions by a farmer have different impacts on California's water supply.

The following scenarios were developed in an effort to estimate the potential consequences for agricultural water demands of modifying cropping patterns and fallowing land. The general purpose of the first set of scenarios was to provide some concrete estimates for the changes that would be necessary to eliminate unsustainable groundwater use. The second set of scenarios provides more comprehensive estimates of the effect of changing cropping patterns on water use and crop revenue.

Table 17

DWR Groundwater Overdraft Estimates

Hydrological Region	1990	2020
	(thousand acre-feet)	
North Coast	0	0
San Francisco	0	0
Central Coast	250	250
South Coast	20	0
Sacramento River	30	30
San Joaquin River	210	0
Tulare Lake	650	590
North Lahontan	0	0
South Lahontan	70	70
Colorado River	80	70
CALIFORNIA TOTAL	**1,310**	**1,010**

All numbers are from DWR 1993, except those for the Tulare Lake Region, which are based on 1994a figures. The 60 thousand acre-feet savings in the Tulare Lake region from 1990 to 2020 is based on the expected overdraft reduction given in DWR 1993.

1. Eliminating Groundwater Overdraft in 2020

In the following agricultural scenarios, we explore how groundwater overdraft could be eliminated by the year 2020 with minimal negative impacts on the agricultural community. Long-term overdraft of groundwater continues to be the major, unsustainable practice in California agriculture. This practice persists because groundwater use is neither monitored nor regulated in most major groundwater basins. To meet the sustainability criteria, a statewide system of groundwater monitoring and regulation must be implemented, and the long-term overdraft of ground water must be eliminated.

To meet the sustainability criteria, a statewide system of groundwater monitoring and regulation must be implemented, and the long-term overdraft of ground water must be eliminated.

Although there are other unsustainable practices associated with agricultural water use, groundwater overdraft has been one of the most persistent. In fact, problems associated with groundwater overdraft have long played a role in justifying major public works, such as the Central Valley Project. Yet in 1990, California still had 1.3 maf of groundwater overdraft, not including emergency pumping due to the drought. According to projections by the DWR, groundwater overdraft can be expected to continue in average water years through 2020. Table 17 shows DWR estimates of overdraft in 1990 and 2020.

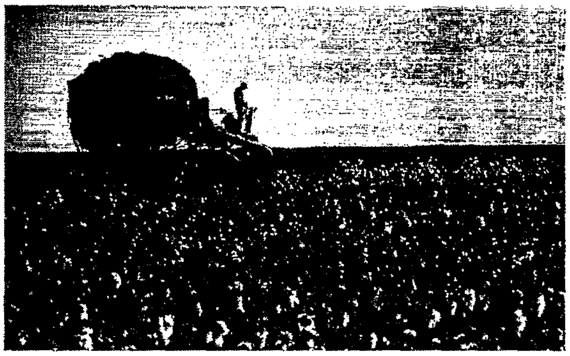
A variety of measures could be used to eliminate groundwater overdraft, including taking more water from rivers and streams or building major new supply projects. These have been the traditional responses. Because the sustainability criteria require maintaining a minimum amount of water for ecosystems, and because new supplies to offset groundwater overdraft are unlikely for political and economic reasons, our analysis focuses on changes in cropping patterns and total irrigated acreage.

Our basic assumptions are fairly straightforward and conservative. We assume no improvement in overall irrigation efficiency, despite the fact that substantial improvements in some areas are both possible and likely. We assume no improvements in crop yields in order to increase revenues, though again, such improvements are both possible and likely. Instead, we focus on shifting crop production away from low-valued, high-water-using crops towards higher-valued, low-water-using crops.

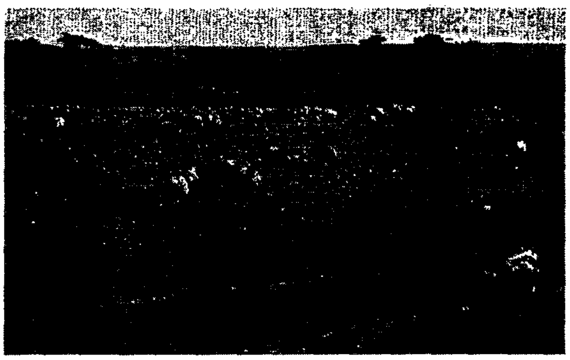
2. Methodology

The two scenarios are based upon reductions in low-value, water-intensive crops: irrigated alfalfa, pasture, rice, and cotton.[11] The first set of projections, the "Balanced Groundwater" scenario, reduces irrigated alfalfa and pasture acreage within each hydrologic region to the point where the amount of water saved equals the amount of groundwater overdraft projected by DWR in 2020. The second scenario, "Agricultural Restructuring," also eliminates groundwater overdraft, but, in addition to reductions in alfalfa and pasture, the acreage of rice and cotton are scaled back to 1960 levels. While the first scenario explores the minimum changes needed to correct groundwater overdraft, the second scenario analyzes the effects of a more streamlined, highly productive agricultural industry.

In each scenario, two water-reduction approaches are used to give a range of estimates of the total irrigated acreage and the economic impacts on agriculture. In the first approach, cropland freed by alfalfa and pasture reductions is left fallow. This method of reducing agricultural water use will have the greatest impact on agricultural revenues and thus produces the worst-case impacts on the agricultural sector. The second approach reallocates cropland to higher-value, lower water-using crops. In this method, acreage of the water-intensive crops are reduced in each region, and the land freed up is proportionately reallocated to the other less water-intensive crops already grown in the region. This method gives a more positive estimate of the impact on agricultural income.[12] The predicted impacts of achieving each scenario's objectives can be reasonably expected to fall somewhere in between the fallowing and crop-switching estimates.



Cotton – a relatively water-intensive, low-valued crop – being harvested near Kettleman City, California. (Courtesy of DWR.)



Cows grazing on irrigation pasture in central California. (Courtesy of DWR.)

We note, however, that many of the complexities associated with crop switching are not accounted for in the scenarios. For instance, economic considerations such as the increased costs of production associated with converting alfalfa and pasture acreage to higher value crops are not considered. Also, a portion of the land in each hydrological region now used to grow these crops is considered marginally productive, and therefore may not be suitable for other crops. For simplicity, it is assumed that in the crop switching cases, all the existing crops in a region can be increased proportionally to make up for acreage reductions in alfalfa and pasture and other low-value water-intensive crops, and that crops not currently grown in a particular region are not introduced.

The scenario calculations are carried out in the following manner. First, average unit evapotranspiration of applied water is computed by

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[11] Although other field crops and corn generate lower revenue per unit consumed water than cotton, they are less water-intensive than cotton. Another reason we chose to reduce cotton acreage in our scenarios is that it is currently the state's largest single crop in terms of irrigated acreage.

[12] The best case economic outcome would come from assuming that all land taken away from water-intensive, low-value crops is reassigned only to the highest valued crop grown in a region. We did not explore this option.

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crop for each hydrologic region using DWR figures (1994a). Then, to calculate consumed water, these unit evapotranspiration figures are multiplied by the projected irrigated acreage for each crop in each hydrologic region. The calculated water use for 2020 using DWR's irrigated acreage predictions serves as the base case scenario. Water savings from our scenarios are compared with this base case.[13]

The impact on agricultural revenue is determined by multiplying the total irrigated acreage of each crop by the average revenue per acre in 1988 as reported in Sunding et al. (1994). The revenue estimates should be considered very approximate. Actual economic impacts will depend on a wide range of factors, including actual market prices, federal subsidy programs, and complicated third-party impacts from switching crop types. More detailed analysis using more sophisticated agricultural market models will ultimately be required to resolve these questions.

3. Balanced Groundwater Scenario (BGS) Results

The main objective of this scenario is to eliminate the estimated annual average one million acre-feet of groundwater overdraft in the year 2020 by reducing alfalfa and irrigated pasture acreage. As shown in Table 17, groundwater overdraft is expected to be a continuing problem in half of the state's ten hydrologic regions. Tulare Lake alone accounts for about 58 percent of the state's groundwater overdraft in 2020. Tables 18 and 19 compare the results of both fallowed land and crop switching cases of the BGS to DWR's 1990 and 2020 estimates.

Compared to DWR's 2020 projections, most of the reductions in irrigated acreage in the fallowed land case occur in the Central Coast and Tulare Lake regions with only small reductions in the Sacramento River, South Lahontan and the Colorado River regions. In this case, the Central Coast and Tulare Lake regions account for 86 percent or 232,000 acres of the statewide reductions in alfalfa and pasture. The Central Coast, in addition to a 100 percent reduction in alfalfa and irrigated pasture, must fallow an additional 115,000 acres of other crops to eliminate groundwater overdraft. The Central Coast is particularly affected because 21 percent of its total water use in the year 2020 is expected to come from overdrafted groundwater. Even if the Central Coast were to grow no alfalfa and pasture in 2020, there would still be over 150,000 acre-feet of overdraft. Loosening the constraints on this analysis somewhat could have permitted fallowing of low-valued crops in other regions and transferring water freed up to the Central Coast region to maintain production of these high-valued crops. In reality, such transfers are likely to occur, but we chose not to include that possibility here.

In the crop reallocation case, reductions in total crop acreage are required only in the Central Coast and Tulare Lake regions. In the other three regions — Sacramento River, South Lahontan, and Colorado River — overall acreage stays the same, but enough water is saved to eliminate groundwater overdraft by proportionally increasing all other crops grown in each region to make up for reductions in alfalfa and pasture. In Tulare Lake, the complete fallowing of alfalfa and irrigated pasture land is offset by a slight increase in acreage of all other crops from the DWR's 2020 projections.

Overall, elimination of groundwater overdraft in 2020 in this scenario requires a reduction in statewide irrigated acreage of only 4.1 percent in the fallowed land case and 3.3 percent in the crop switching case. What is the cost to agricultural producers to achieve this groundwater balance? Intuitively, one would think that severe negative economic impacts would coincide with significant reductions in water and land use by the agricultural sector. In fact, at the state level, the opposite is true. Using 1988 estimates of crop farm revenues, this scenario results in a net farm revenue increase from 1990 of $149 million in the fallowed land case and $454 million in the crop switching case, as higher-valued crops begin to substitute for alfalfa and pasture. The growth in farm revenue in the crop switching case

[13] Our calculations of consumed water do not match agricultural water use figures in DWR's Bulletin 160-93 report because our method of calculating total consumed water does not include additional "irrecoverable losses." These losses are included in the DWR's "depletion" figures for the state (DWR 1994a). By reducing overall consumed and applied water use in agricultural, these losses will be reduced by our approach as well.

Table 18
Balanced Groundwater Scenario: Comparision of Irrigated Crop Acreage, Consumed Water, and Revenues for 1990 and 2020

Crop Area Irrigated (thousand acres)

Hydrological Region	1990 DWR[a]	2020 DWR[a]	2020 Balanced Groundwater Scenario Fallowed Land	2020 Balanced Groundwater Scenario Crop Switching
North Coast	326	346	346	346
San Francisco	61	64	64	64
Central Coast	528	566	412	412
South Coast	319	184	184	184
Sacramento River	2,145	2,186	2,175	2,186
San Joaquin River	2,008	1,952	1,952	1,952
Tulare Lake	3,212	3,061	2,871	2,911
North Lahontan	161	169	169	169
South Lahontan	61	48	32	48
Colorado River	749	726	713	726
California Total	**9,570**	**9,302**	**8,918**	**8,998**

Water Consumed (thousand acre-feet)

Hydrological Region	1990 DWR[a]	2020 DWR[a]	2020 Balanced Groundwater Scenario Fallowed Land	2020 Balanced Groundwater Scenario Crop Switching
North Coast	504	553	553	553
San Francisco	67	67	67	67
Central Coast	758	800	551	551
South Coast	544	320	320	320
Sacramento River	4,745	4,783	4,754	4,754
San Joaquin River	4,014	3,703	3,703	3,703
Tulare Lake	7,001	6,431	5,841	5,841
North Lahontan	393	408	408	408
South Lahontan	248	204	134	134
Colorado River	2,987	2,876	2,806	2,806
California Total	**21,261**	**20,147**	**19,137**	**19,137**

Crop Revenue (million 1988 dollars)

Hydrological Region	1990 DWR[a]	2020 DWR[a]	2020 Balanced Groundwater Scenario Fallowed Land	2020 Balanced Groundwater Scenario Crop Switching
North Coast	265	304	304	304
San Francisco	127	138	138	138
Central Coast	1,461	1,600	1,237	1,237
South Coast	822	500	500	500
Sacramento River	1,839	1,999	1,995	2,034
San Joaquin River	2,367	2,593	2,593	2,593
Tulare Lake	4,123	4,439	4,348	4,486
North Lahontan	66	73	73	73
South Lahontan	40	27	20	91
Colorado River	1,082	1,137	1,131	1,188
California Total	**12,191**	**12,811**	**12,340**	**12,645**

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

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[illegible]

Crop	1990 DWR	2020 DWR	Balanced Groundwater Scenario Fallow Land	Balanced Groundwater Scenario Crop Switching
Grain	988	909	904	928
Rice	517	498	498	513
Cotton	1,244	1,194	1,194	1,236
Sugar Beets	216	197	196	202
Corn	403	409	408	415
Other Field	491	455	452	464
Alfalfa	1,135	947	725	622
Pasture	956	813	766	724
Tomatoes	352	338	335	343
Other Truck	1,021	1,251	1,175	1,214
Almond/Pistachio	510	561	561	572
Other Deciduous	570	585	581	615
Subtropical	419	392	389	394
Grapes	748	753	735	752
TOTAL CROP AREA	**9,570**	**9,302**	**8,919**	**8,998**

Source: DWR numbers are from DWR 1994a.

would have been even higher but for the decrease in farm revenues from the Central Coast region. This cost to agriculture in the Central Coast area must be weighed against the potentially far worse economic effects of continued groundwater overdraft in the region, which could lead to salt-water intrusion in some areas, rendering groundwater supplies unsuitable for farming. Compared to the agricultural revenues implied by DWR's 2020 crop mix, agricultural revenue in California in the fallowed land case is only 3.7 percent less than with the groundwater overdraft. In the crop reallocation case, state agricultural revenues only drop 1.3 percent. This range of costs to eliminate groundwater overdraft are indeed small considering the benefits of sustainable agricultural water use.

4. Agricultural Restructuring Scenario (ARS)

While the Balanced Groundwater Scenario gives an indication of the changes necessary to minimally fulfill the sustainability criteria, the Agricultural Restructuring Scenario (ARS) explores the sensitivity of agricultural water demand and revenue to further changes in state cropping patterns. In addition to saving 1.01 maf of groundwater overdraft as described above, this scenario explores further reductions in the acreage of two other water-intensive, low-value crops — cotton and rice. DWR projects only slight declines of 698,000 acres (about 4 percent) of rice and cotton acreage between 1990 and 2020. We assume that between 1990 and 2020 irrigated rice and cotton acreage is slowly reduced by about one-third, back to the levels planted in 1960 — a comparable 30-year period of change. In 1960 there were 375,000 acres of rice and 810,000 acres of cotton irrigated statewide. Irrigated pasture, which decreased in acreage by about 40 percent between 1960 and 1990 is assumed to drop another 40 percent over the next 30 years. We assume that the acreage of alfalfa, which drops 45 percent between 1990 and 2020 in order to eliminate groundwater overdraft in the Balanced Groundwater Scenario, drops no further. These assumptions envision California agriculture as a highly productive and efficient enterprise, using much less water overall to produce more higher-value crops. Tables 20 and 21 summarize the results of this scenario.

In the ARS fallowing case, all ten hydrologic regions experience reductions in irrigated acreage compared to DWR's 2020 forecast. The decrease of 119,000 acres of rice in the Sacramento River region accounts for most of

Table 20
Agricultural Restructuring Scenario: Comparison of Irrigated Crop Acreage, Consumed Water, and Revenues for 1990 and 2020

Crop Area Irrigated (thousand acres)

Hydrological Region	1990 DWR[a]	2020 DWR[a]	2020 Agricultural Restructuring Scenario	
			Fallowed Land	Crop Switching
North Coast	326	346	315	346
San Francisco	61	64	63	64
Central Coast	528	566	412	412
South Coast	319	184	183	184
Sacramento River	2,145	2,186	1,977	2,186
San Joaquin River	2,008	1,952	1,848	1,952
Tulare Lake	3,212	3,061	2,565	3,058
North Lahontan	161	169	143	169
South Lahontan	61	48	29	48
Colorado River	749	726	685	726
California Total	**9,570**	**9,302**	**8,219**	**9,145**

Water Consumed (thousand acre-feet)

Hydrological Region	1990 DWR[a]	2020 DWR[a]	2020 Agricultural Restructuring Scenario	
			Fallowed Land	Crop Switching
North Coast	504	553	491	529
San Francisco	67	67	65	66
Central Coast	758	800	551	551
South Coast	544	320	316	319
Sacramento River	4,745	4,783	4,161	4,478
San Joaquin River	4,014	3,703	3,418	3,592
Tulare Lake	7,001	6,431	5,073	5,841
North Lahontan	393	408	342	389
South Lahontan	248	204	121	134
Colorado River	2,987	2,876	2,697	2,790
California Total	**21,261**	**20,147**	**17,233**	**18,687**

Crop Revenue (million 1988 dollars)

Hydrological Region	1990 DWR[a]	2020 DWR[a]	2020 Agricultural Restructuring Scenario	
			Fallowed Land	Crop Switching
North Coast	265	304	294	332
San Francisco	127	138	138	140
Central Coast	1,461	1,600	1,237	1,237
South Coast	822	500	499	503
Sacramento River	1,839	1,999	1,911	2,200
San Joaquin River	2,367	2,593	2,533	2,692
Tulare Lake	4,123	4,439	4,113	5,171
North Lahontan	66	73	64	86
South Lahontan	40	27	19	91
Colorado River	1,082	1,137	1,112	1,241
California Total	**12,191**	**12,811**	**11,920**	**13,693**

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

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Table 21
Agricultural Restructuring Scenario: Comparison of Irrigated Acreage by Crop for 1990 and 2020 Scenarios (thousand acres)

Crop	1990 DWR	2020 DWR	Agricultural Restructuring Scenario: Fallow Land	Agricultural Restructuring Scenario: Crop Switching
Grain	988	909	904	1,088
Rice	517	498	375	375
Cotton	1,244	1,194	810	810
Sugar Beets	216	197	196	227
Corn	403	409	408	474
Other Field	491	455	452	534
Alfalfa	1,135	947	725	622
Pasture	956	813	574	574
Tomatoes	352	338	335	393
Other Truck	1,021	1,251	1,175	1,355
Almond/Pistachio	510	561	561	655
Other Deciduous	570	585	581	707
Subtropical	419	392	389	458
Grapes	748	753	735	872
TOTAL CROP AREA	**9,570**	**9,302**	**8,219**	**9,145**

Source: DWR numbers are from DWR 1994a.

the reductions in irrigated rice. Nearly all of the 384,000 acres of reductions in cotton occur in the San Joaquin River and Tulare Lake regions.

In the ARS crop switching case, reductions in total crop acreage occur only in the Central Coast and Tulare Lake. The Central Coast's crop mix is the same in all four scenario cases because of the required fallowing of other crops in order to stop overdraft. Because the Tulare Lake area is the main cotton-producing region in the state, the large reduction in cotton from DWR's 2020 estimates frees up enough water to bring back into production 146,000 of the 150,000 acres of the land fallowed in the Balanced Groundwater scenario's crop switching case. Also worth noting is that the South Lahontan region significantly shifts crop types because of a high present concentration of alfalfa and pasture production.

Statewide, the fallowed land case in the ARS scenario sees a significant 14.1 percent decrease in irrigated acreage from 1990. Meanwhile, consumed water is reduced over 4 maf from DWR's 1990 projections and 2.9 maf from their 2020 figures. The results of the ARS crop reallocation case are the most positive of all the cases in both scenarios. Because additional crops are grown in place of the reduced cotton, rice, alfalfa, and pasture acreage, irrigated acreage statewide falls only 4.4 percent from 1990 and only 1.7 percent compared to DWR's 2020 number. In terms of consumed water, this case saves 2.6 maf compared to 1990 and 1.5 maf compared to DWR's projected 2020 agricultural water consumption.

The range of impacts on agricultural revenue of the fallowed land and crop switching cases is quite large. In the fallowed land case, revenue decreases only 2.2 percent compared to 1990 but 7.0 percent compared to DWR 2020 projections. In the crop switching case, agricultural revenues actually increase by 12.3 percent over 1990 and 6.9 percent over DWR's 2020 projections. Even the Tulare Lake region, which undergoes massive cropping adjustments in this scenario's crop switching case, shows an increase in revenues of 16.5 percent over DWR's 2020 projections.

5. Summary

These two scenarios, the Balanced Groundwater Scenario and the Agricultural Restructuring Scenario, give a range of the possible changes in irrigated acreage and impacts on agricultural income of achieving sustainable water use in the agricultural sector. Table 22 summarizes the basic findings of these calculations. In general, the statewide impacts on total irrigated acreage and total revenue are small, although specific regions such as the

Central Coast and Tulare Lake are disproportionately affected in the fallowing cases. In the most optimistic crop switching case of the Agricultural Restructuring scenario, 1.5 maf of water are saved with only a 1.7 percent decrease in irrigated acreage compared to DWR's 2020 projections. Meanwhile, total revenues are estimated to be $882 million higher than the $12.8 billion in revenues estimated using DWR's 2020 projections. Even in our worst case, the fallowing case of the Agricultural Restructuring Scenario, total agricultural revenues decrease only seven percent compared to revenue estimates using DWR's 2020 forecast. While the Institute recognizes that it is impossible to accurately predict the price of specific farm products thirty years into the future, the basic trends hold true. An increase in the production of high-value, labor-intensive crops such as fruits and market vegetables and a reduction in low-value crops such as alfalfa and irrigated pasture will help California's agricultural economy.

Thus, for the vision of 2020 presented at the outset of this report, we believe that the crop switching case of the Agricultural Restructuring Scenario is feasible. While this scenario is optimistic, these changes are still modest compared to what could be done, such as serious changes toward efficient production, low-water using crops, greenhouse production, ornamental exports, and aggressive crop genetics. We chose not to explore these more aggressive possibilities. To give an idea of how little we really changed the agricultural sector, even under the ARS scenario alfalfa, irrigated pasture, cotton, and rice will still account for 29 percent of California's irrigated acreage and 38 percent of the state's agricultural consumed water. This future vision is one of a more highly productive agricultural sector that uses water much more efficiently, but it still looks much like the one that exists today.

While we calculate only the direct impacts of these scenarios, the actual affects on the farmers and the surrounding communities will depend on the measures used to accomplish them. In particular, we did not analyze the indirect impacts on associated industries such as livestock and dairy, agricultural employment, and those living in rural agricultural communities. These effects are important and must be considered in fashioning paths toward the future we envision. Crop and water subsi-

Table 22

Summary of Balanced Groundwater and Agricultural Restructuring Scenarios

Balanced Groundwater Scenarios

California Totals	1990 DWR	2020 DWR	2020 Fallow Land	Percent Change 1990-Fallow Land	2020 Crop Switching	Percent Change 1990-Switching
Irrigated Acreage (thousand acres)	9,570	9,302	8,918	-6.8	8,998	-6.0
Agricultural Consumed Water (thousand acre-feet)	21,261	20,147	19,137	-10.0	19,137	-10.0
Total Revenue (million 1988 dollars)	12,191	12,811	12,340	1.2	12,645	3.7

Agricultural Restructuring Scenarios

California Totals	1990 DWR	2020 DWR	2020 Fallow Land	Percent Change 1990-Fallow Land	2020 Crop Switching	Percent Change 1990-Switching
Irrigated Acreage (thousand acres)	9,570	9,302	8,219	-14.1	9,145	-4.4
Agricultural Consumed Water (thousand acre-feet)	21,261	20,147	17,233	-18.9	18,687	-12.1
Total Revenue (million 1988 dollars)	12,191	12,811	11,920	-2.2	13,693	12.3

Source: DWR 1994a and Pacific Institute Analysis.

dies and their role in sustaining small family farmers and agricultural employment should also be considered. The possibility of investing the gains from water transfers and environmental restoration into rural community and economic development should be explored. Finally, new programs to encourage agricultural practices that save water, increase economic opportunities, and protect the environment need to be implemented.

C. SUSTAINABLE ENVIRONMENTAL WATER USE

Human development has forever changed California's natural environment. Urbanization, agriculture, and the creation of extensive water infrastructure to supply our cities and industries have all transformed natural ecosystems. In some cases, shrinking habitats, polluted air and water, or changes in natural water flows have forced species into extinction. In other cases, humans have been able to coexist to varying degrees with the surrounding flora and fauna. Because water resources are so vital for environmental quality, the sustainability criteria presented in Section III require that water quantity and quality be explicitly and flexibly managed to maintain the health of ecosystems.

Water policy should be designed to avoid irreversible environmental impacts, such as species extinction and destruction of unique habitats. The key to such a strategy is flexibility.

Determining exactly what environmental water requirements should be, however, is an extremely difficult task. First, scientific information must be gathered about the complex interactions among water quality and quantity, and ecosystem health. Then, societal judgments need to be made about what level of ecosystem health is "enough" if other societal goals conflict with maintaining pristine ecosystems. Finally, other water-management questions will have to be answered: how much water is needed to meet environmental goals during average and drought years, which human and environmental purposes can be fulfilled simultaneously, and at what times should water be allocated during each season? Far better knowledge of natural processes and human interactions will be needed to guide these decisions.

While the scientific understanding needed for good management is improving, there are still great uncertainties in determining environmental water requirements. In the absence of scientific certainty, it is advisable to take a precautionary approach towards the environmental implications of water management. In particular, water policy should be designed to avoid irreversible environmental impacts, such as species extinction and destruction of unique habitats. The key to such a strategy is flexibility. The rest of this section describes the process that we believe should guide sustainable environmental water management.

1. Determining Environmental Water Needs

The ecosystems for which water must be maintained include both natural ecosystems where there is minimal human interference and ecosystems that are highly managed by humans. In some cases, water needed for environmental purposes will exclude consumptive human uses, such as when society chooses to preserve free-flowing rivers. In many other cases, environmental goals will be reached while also pursuing human uses. For example, flooding rice fields improves rice production, while simultaneously providing wildlife habitat and satisfying air quality concerns. However, because environmental water needs can sometimes be met in conjunction with human needs, and because the timing of environmental water allocations must vary seasonally and year-to-year, it is sometimes difficult to accurately quantify ecosystem water needs in the same manner as urban and agricultural water demands. Societal decisions will have to be made regarding the degree to which ecosystems should be maintained or restored and the indicators by which to measure ecosystem health.

Rather than viewing ecosystems as direct competitors for water resources, an integrated management framework should be adopted. In this framework human and ecosystem uses are considered together and, where possible, are satisfied simultaneously. Managing water and environmental resources in an integrated way makes sense since each region is connected by the flow of water. Activities upstream can have severe impacts on ecosystems and economic production downstream. Properly integrated watershed planning can maintain the adequate mosaic of habitat to sustain environmental goals as well as to allow economic development in appropriate and manageable areas.

Various environmental goals have already been set by public actions and are described in Section IV. These goals 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, protection of wetlands and endangered species, and restoration of certain anadromous fisheries as required by the CVPIA. In December 1994, after years of negotiations, an interim agreement was reached on quality and outflow requirements in the Bay-Delta, although questions about implementation of the plan still remain to be resolved. These acts are only the beginning of a new era of joint water and environmental management.

Achieving these goals will require political consensus and flexible institutional structures. Ultimately, management will have to follow an adaptive model where decisions are to be reviewed frequently based on the latest information and caution is to be exercised with respect to possible irreversible actions. Standards and indicators of ecosystem health need to be further identified, improved upon, and monitored on a continuous basis. Monitoring can be accomplished through networks and coalitions of both governmental and non-governmental agencies.

2. Environmental Vision 2020

By 2020, California's natural environment can be substantially revitalized. Because total urban and agricultural water use can remain constant or decline between 1990 and 2020, more water can be made available to protect preserved rivers, streams, and wetlands, restore aquatic, wetland, and riparian habitats, sustain populations of threatened and endangered species, and maintain water quality. Specifically, water in California's Wild and Scenic Rivers must continue to be protected at both the state and federal levels. Long-term Bay/Delta standards that include both technical and institutional approaches to protect vulnerable species at certain times of the year and to maintain water quality should replace the interim standards. Water should be allocated to restore some of the native anadromous fish runs in the San Joaquin River and elsewhere. There should be no further net loss of wetlands, greater efforts should be made to restore degraded wetlands, and sufficient water should be reserved for protected wetlands. Opportunities for the integrated management of agriculture and seasonal wetlands should be pursued further. And, as an added goal, attempts should be made to return high-altitude mountain waters to pure, drinkable conditions.

Much effort is required to restore ecosystems that have been severely damaged by past water development. How much restoration and at what quality will have to be guided by a democratic political process that includes local communities. When local communities are adversely impacted by restoration efforts, funds should be made available to mitigate the impacts. Through improved private and public stewardship of our natural resources, California can pursue more environmentally-compatible forms of economic activity.

Land-use planning and water-resources management must be explicitly linked, even in remote areas normally thought of as pristine. For example, an appropriate goal, described briefly in the opening Vision section, is to restore drinkable streams to the Sierra Nevada. In recent years, the formerly pristine streams of the high mountains have become contaminated and can no longer be used for drinking without some form of treatment because of cattle grazing, large numbers of human users, and poor sanitary behavior. Restoring these streams to drinkable levels would require more comprehensive land-

Melting snow in the Sierra Nevada provides much of California's water. (Courtesy of DWR.)

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management policies on the part of land managers and better education of the users of that land.

For urban and rural development, land-use management is also a vital component of proper water management. Rather than building first and then finding the water, the potential demands for water from proposed developments should be assessed in the planning stages. Developers should have to demonstrate that they have a secure and adequate supply of water that will not require further environmentally-harmful water development.

Lastly, areas that are largely undeveloped should be preserved and protected for future generations. The State and Federal Wild and Scenic Rivers acts already accomplish this objective to some degree. Lands under federal and state management should be identified for wilderness designation, with the highest priority given to those watersheds that are most critical to maintaining water quality, endangered species, or vital habitat.

Table 23

Comparison of Water Balances for DWR and 2020 Vision

California	DWR 1990	DWR 2020	Vision 2020
	million acre-feet		
Net Water Demand[a]			
Agriculture[b]	26.8	24.9	23.3
Urban[c]	6.8	10.5	8.2
Societal Net Demand	33.6	35.4	31.5
Other Net Water Demands[d]			
Wetlands	1.1	1.3	1.3
Additional Bay/Delta Outflow	0.0	1.0	1.0
Other[e]	1.5	1.5	1.5
Total Demands	36.2	39.2	35.3
Total Supply[f]	35.1	36.9	37.5
Total Supply minus Demand	-1.1	-2.3	2.2

Source: DWR (1994a) and Tables 1 and 2.

[a] *Net Water Demand equals the sum of water consumed, irrecoverable losses, and agricultural return flow or treated municipal outflow leaving an area.*

[b] *Net agricultural demand for 2020 Vision calculated by adding irrecoverable losses and outflow to Table 1's 2020 Consumed Water estimate. Irrecoverable losses are calculated at the same percentage of net demand as DWR's 2020 projection. Outflow is assumed to be the same as for DWR's 2020 projection.*

[c] *Net urban demand for 2020 Vision is the same as Table 2's 2020 Total Applied Urban Water Use. We assume no reuse of water other than our estimates of reclaimed water use.*

[d] *2020 Vision assumes that Other Demands are the same as DWR 2020.*

[e] *Other includes major conveyance losses, recreation uses, and energy production.*

[f] *Total supply for DWR includes reclaimed water. The 2020 Vision figure includes our higher estimate of reclaimed water.*

3. Summary

Where will the water come from to achieve this vision? While the DWR predicts that the net agricultural and urban water demands will total 39.2 maf in 2020, our vision as summarized in Table 23 projects a combined net water demand of only 35.3 maf. Compared to projected average year supply of 37.5 maf, we project no gap between supply and demand. Rather, there is a modest cushion of 2.2 maf, which can remain flowing in rivers and streams. Furthermore, intelligent use of reclaimed water may permit a further reduction in potable water requirements in urban and agricultural communities, decreasing pressure on natural ecosystems during droughts. Our vision is, therefore, accomplished through conscientious and feasible urban and agricultural water-saving strategies.

VI. How Do We Get There: Technologies and Practices for Sustainable Water

A desirable vision of the future is of limited value without any guidance how to get there. The vision laid out at the beginning of this report was developed making straightforward assumptions about the role and availability of technology, the applicability of different policies, and the behavior of institutions. There is no need to assume any magic formulas or new technologies to reach a sustainable water future; nor is there any need for heroic actions on the part of any individuals, organizations, or sectors. The kinds of decisions and institutions necessary to move toward this positive vision are little different from the kinds of choices already available. This is the good news. The bad news is that there is no assurance that policymakers and the public will agree on the goals to seek or on the ways to reach them. This section offers some guidance for the kinds of tools that have proven effective in California and elsewhere that would move toward achieving the vision described above.

A. TECHNOLOGIES AND PRACTICES TO REDUCE WATER REQUIREMENTS

Water-using technologies play an important role in determining the level of water needed to satisfy particular demands. As a result, attention has focused in recent years on both understanding water demands and on developing and marketing new, more water-efficient technologies to meet these demands. Many such technologies are available for every sector, ranging from low-flow toilets to electronic controllers on irrigation equipment to sophisticated changes in industrial processes.

If no technologies are available on the market, they must be developed to commercial levels. If they are on the market but too expensive, their costs to the consumer must be reduced. Financial or regulatory incentives can be provided to manufacturers to speed product development, optimize production, and thus reduce market prices. Incentives can be provided to water agencies to purchase these technologies and install them for customers. Incentives can be provided to industry to alter water-using processes. And incentives can be offered to individuals to purchase and install equipment to reduce water demand. Savings are available in every sector. Technologies and business practices in which water-efficiency improvements are available are described below for a variety of sectors.

1. Residential Sector

a) Residential Bathroom and Kitchen Fixtures

For several years now, electric utilities have been developing and offering a wide range of programs to try to save energy by increasing residential energy-use efficiency. These programs include educational programs, improved availability of efficiency equipment for customers, the direct installation of such equipment, and audit programs. The same potential exists for water, and water utilities are now beginning to implement similar activities. In addition to water savings, improved water-use practices can also save substantial energy and reduce investments in wastewater treatment programs.

The kinds of decisions and institutions necessary to move toward this positive vision are little different from the kinds of choices already available. This is the good news. The bad news is that there is no assurance that policymakers and the public will agree on the goals to seek or on the ways to reach them.

Some water utilities are now beginning to offer direct distribution and installation of water-efficiency technologies, at no cost to consumers. Many of these technologies are more cost effective than building new infrastructure, with rapid paybacks to the utility from water and energy savings. For utility programs, few new financial incentives are likely to be necessary, though the cost of operating the programs should be recoverable.

There is a direct connection between increased efficiency of water use and other sustainability goals, such as increasing energy efficiency. For example, reducing water use in residential and commercial bathrooms and kitchens will have a direct effect on reducing energy use for heating water, and on the emissions of air pollutants from that energy use. Table 24 shows an estimate of the average U.S. reductions in water use expected to result from the conversion of residential water fixtures to more efficient models, as required by the National Energy Policy Act of 1992. Also shown in this Table are the anticipated reductions in utility electric energy demands associated with that water use and the per-capita emissions of carbon dioxide, nitrogen oxides, and sulfur dioxide (Vickers 1993).

Table 24

Water Use, Energy Demand, and Atmospheric Pollutants Associated with Residential Plumbing

Period	Maximum Daily Water Use (gallons/capita)	Utility Annual[b] Electrical Demand (kWhr/capita)	Annual Atmospheric Emissions (lbs/capita/kWhr)
Pre-1980 Fixtures	54.5	57	110.7
1980-1994 Fixtures	33.9	35	68.7
Post-1994 Fixtures[a]	21.4	22	43.4

[a] *Using 1.6 gallons/flush toilets, 2.5 gallons per minute showerheads, and 2.5 gallons per minute faucets.*

[b] *For heating water.*

Source: Vickers 1993.

Over 77 percent of all indoor residential water use in California goes to toilets, faucets, and showerheads. A wide range of water-efficiency devices are available on the market, including ultra-low flow toilets and showerheads, toilet tank displacement "dams," and faucet aerators. For the most part, these devices are inexpensive, and many manufacturers are beginning to compete for the growing market. For example, in 1993 the Rocky Mountain Institute reported that there were over 17 manufacturers of high-efficiency showerheads producing over 30 different models (Jones 1993). The largest barrier to wide distribution of these devices appears not to be their cost, but lack of information about their savings, concern about their quality, and uncertainty about how to acquire and install them (Gleick, Stewart, Norman 1994). Programs that focus on reducing these barriers are needed.

Ultra-low flow toilets (ULFT) can reduce the amount of water required to dispose of wastes by as much as 75 percent and are now required by the 1992 NEPAct. While this will change the water use in new construction and remodels, additional incentives or ordinances may be needed to get ULFT into existing buildings. In this case, additional financial incentives to manufacturers, distributors, builders, and contractors can increase their penetration into the retrofit market. Some water agencies and utilities are offering some form of rebate to encourage customers to purchase and install ULFTs. The rebate can be a flat dollar amount, a percent of the sales price, or a flat rate depending on the toilet price (e.g., $50 for a $200 toilet, $100 for a more expensive toilet). The Metropolitan Water District of southern California, for example, offers its member agencies a one-time $154 per acre-foot of water saved in programs to retrofit low-flow toilets (T. Quinn, Metropolitan Water District, personal communication, 1994).

At the extreme end of the spectrum are composting toilets that generally need no sewer hook-up, septic system, or plumbing. While these toilets are larger than conventional toilets, they may be attractive options in remote applications and sites with special plumbing limitations. They may also be useful in small cottages or cabins where they are only used periodically, though some designs function best when used continuously (Rocky Mountain Institute 1993). Composting toilets reduce water used for flushing to zero, thus eliminating about 35 percent of typical residential indoor water requirements.

b) Residential Appliances

Several major indoor household appliances such as dishwashers and washing machines consume substantial amounts of water. Unlike residential bathroom fixtures, the number and quality of water-efficient appliances available for sale are small, and their costs, relative to their water-inefficient cousins, are high. Strong incentives are needed to encourage manufacturers and distributors to increase market availability and share for these appliances, and for consumers to purchase and install them.

Several manufacturers are now beginning to explore more efficient appliances, such as horizontal-access washing machines. This technology appears to be a particularly strong candidate for direct financial incentives, though additional research is necessary to more precisely quantify actual water and energy savings in home use. Horizontal-axis clothes washers have long been popular in Europe and are now beginning to enter the U.S. market. At least one U.S. manufacturer, Frigidaire/White Westinghouse, produces a full-size, front-load, horizontal-axis machine, though a second company, Staber, is introducing a machine. By some estimates, when compared with typical top-loading machines, these machines require only one-third as much detergent and bleach, two-thirds as much total water, and one-third as much hot water and energy for a comparable load of wash (Shepard 1992). Because of the low-volume production, extra shipping costs, and more complex electronics and timing mechanisms compared to top-loading machines, horizontal-access machines cost substantially more to produce. Some industry experts believe, however, that due to economies of scale, there may be no significant price difference under full production. In 1992, Southern California Edison offered a $75 rebate for horizontal-axis washers, and the Seattle Water Department is considering a rebate to manufacturers to increase commercial availability of these machines (A. Jones, Rocky Mountain Institute, personal communication, 1994, Barakat and Chamberlin 1994).

A major joint study by Seattle City Light, the Seattle Water Department, and various utilities and manufacturers is now underway to evaluate horizontal-axis machines. The study will include a laboratory analysis of actual performance, an in-home end-use study, and an assessment of market barriers to adoption of efficient machines. There is a strong feeling, however, that a market transformation is needed to bring costs of efficient machines down to a comparable level with present machines (S. Hill, Seattle Water, personal communication, 1994). There are many ways to do this, such as providing rebates to customers who purchase such machines, rebates to the manufacturer to make up the difference in cost with conventional systems, or efficiency standards. Recent U.S. policy actions have focused on the development of new standards for manufacturers, and a national committee comprised of utilities, manufacturers and federal regulators is now working to identify efficiency standards for large residential appliances to go into effect near the turn of the century.

c) Residential Landscape Water Use

The high use of water for lawns suggests that paying attention to the efficiency of lawn and garden irrigation may produce large water savings in the residential sector. Typical residential irrigation methods are estimated to be only 50 to 80 percent efficient, with the remainder of the water evaporating, running off the landscape, or percolating to deeper soil levels. These low efficiencies suggest considerable room for improvement. Simply correcting these inefficiencies could result in as much as a 50 percent savings in outdoor water use. Incentives to install efficient watering equipment, or to replace high-use lawns with drought-tolerant plants (xeriscaping), are also effective ways to reduce residential water needs. Table 25 lists options for landscape efficiency programs.

Among the barriers to improving residential irrigation efficiency are lack of information to consumers on actual watering requirements, low prices for water, and lack of incentives for architects, designers, builders, and managers to implement and operate more efficient systems.

Past approaches to reducing landscape water use included watering restrictions and other measures that often led to decreases in garden quality. More recent efforts focus on maintaining the function and quality of landscapes while reducing their water demands, such as through changes in technology, changes in plant types, and more sophisticated operation. Recent experience has documented that water-efficient landscaping not only reduces water demand, but reduces the need for fertilizers, herbicides, fuel, and labor. For example, a 1990

Table 25
Common Options for Landscape Water-Efficiency Programs

Design and Management Opportunities	Utility Program Options
Alternative supplies (gray- or reclaimed water)	Awards
Computer-controlled irrigation	Demonstration gardens and landscapes
Computerized plant selection	Design requirements for new building
Drip irrigation and improved sprinklers	Educational videos and pamphlets
Improved irrigation scheduling	Landscape water-use audits
In-depth planning and design	Ordinances and restrictions
Landscape design software	Rebates
Lawn de-thatching and aeration	Seminars and workshops
Limited fertilization	Training for landscape professionals
Limited turf areas and taller grass	
Moisture meters	
Proper maintenance	
Rock gardens, decks, and patios	
Soil conditioning and mulching	
Subsurface irrigation	
Use of native plants	

(Source: Chapin 1994)

study comparing conventional and water-efficient landscapes in northern California documented savings of 54 percent for water, 25 percent for labor, 61 percent for fertilizer, 44 percent for fuel, and 22 percent for herbicides (Chapin 1994).

The cost of improving residential irrigation efficiency can be borne by different users, including water utilities, homeowners, and builders. Water utilities can invest in such improvements rather than investing in new supply. Homeowners can invest to reduce water use and water bills. When building new homes, the cost of installing water-efficient landscaping can be approximately equal to the cost of installing conventional landscaping, and can be *made* approximately equal by a set of financial incentives when the costs are higher.

Financial incentives to manufacturers to produce more efficient equipment at competitive prices, or rebates to consumers to purchase such equipment can increase market shares. For example, a wide range of computer controllers for lawns are available, in varying degrees of sophistication, ranging from simple battery-operated devices for home use that function on the time-of-day principle to central computer control systems, capable of integrating on-line information on weather forecasts together with real-time information from moisture sensors in the ground. These more advanced systems are only useful for very large landscapes and irrigators. In some circumstances, incorrect use of these timers can lead to overwatering and an increase in residential water use (Henggeler 1991).

2. Industrial, Municipal, and Institutional Sectors

a) Industrial, Municipal, and Institutional Water-Use Equipment

A wide range of water-efficient technologies or business practices are becoming available for the industrial and commercial sectors. Some of these, such as efficient cooling towers, are general to many industries; others, such as commercial laundering, are specific to particular sectors. Both general and specific examples are discussed below, but overall, incentives to install more water-efficient technologies and to alter practices to reduce water demand can be effective in all sectors. This is particularly true where new technologies are beginning to appear and where the need for both education and information on alternatives remains high.

Industrial and municipal water use for heating, ventilation, and cooling requirements can be high. For southern California and other semi-arid regions, cooling towers often use one-third to one-half of all water, yet these systems are often poorly managed and operated, relying on few or no electronic controls and once-through cooling (J. Sweeten, Metropolitan Water District, personal communication, 1994). Incentives to alter operating styles, to increase reuse by increasing system passes, or to install control systems can often save substantial quantities of water, as well as reduce the cost of wastewater disposal. In addition, some new technologies, such as ozone treatment of cooling tower water for disinfecting without chemicals, may appear on the market with modest economic encouragement. These systems may increase energy use compared to conventional systems, so the tradeoff between higher energy use and lower chemical use must be carefully evaluated.

The Metropolitan Water District, for example, suggests that process cooling water requirements in a section of the primary metals industry in its operating area can be reduced from over 110 million gallons per year to under 30 million gallons per year with a simple payback period of 4.8 years (MWD 1994). Similar savings are available in other industrial sectors as well.

Other high-volume commercial and institutional water users worth further study include laundries, car washes, sports/fitness centers, certain fast-food restaurants, and toilets in commercial and industrial locations. Incentives are needed to improve the market availability and penetration of more efficient technologies, such as those that can replace one-pass coolers for compressors (as used in hotel icemakers).

As an example, commercial laundries use substantial amounts of water, and energy to heat that water. Like the residential sector, some efficient machines are available on the market, but they have not achieved significant market share because of higher costs and limited selection. In particular, the use of horizontal-axis commercial machines is limited to large-capacity uses. More attention to this market, as mentioned earlier in the residential section, could produce significant savings (S. Hill, Seattle Water, personal communication, 1994).

There have recently been some dramatic claims about the ability of "ozonated laundering" to practically eliminate both hot water and detergent use, with savings on water costs, energy, chemicals, labor, and sewage fees. Initial user reports are favorable, but far more research is needed on how the approach works, how reliable it is, and what the best applications are. Reports from two Marriott hotels in Florida indicate that laundry could be done in 118° F water, rather than 140° F water, with detergents and bleaches almost completely eliminated. Water used dropped from 3.5 gallons of water per pound of laundry to 1.6 gallons of ozonated water per pound with comparable reductions in sewer costs. An increase in electricity use partially offsets these savings. According to Christensen (1993), laundry industry publications are giving cautious but increasingly positive reports of this technology.

b) Municipal, Industrial, and Institutional Landscape Water Use

Large "turf" irrigators often consume substantial amounts of water, particularly in the western United States. Reducing water demand by these users is in part a question of modifying taste and behavior, and in part a question of installing alternative technologies, such as dual systems for reclaimed water, buried precision irrigation equipment, and more flexible systems to control the application of water. Among the equipment that could, or should be available for improving the efficiency of large turf irrigation are more "intelligent" automatic controllers, which work together with moisture sensors that monitor actual water needs. Incentives need to be directed at equipment producers, at home buyers and sellers, and at builders.

A wide range of computer controllers for irrigating large areas of turf are already available, in varying degrees of sophistication. All of these systems benefit from the training of users; none are "set and forget" systems, though advances are likely to produce such systems in the next several years. At the extreme, one can purchase central computer controlled systems, capable of integrating online information on weather forecasts together with real-time information from moisture sensors in the ground. An example of these more advanced systems is the California Irrigation Management Information System (CIMIS), which links irrigators with a statewide data bank of weather information. These data permit more accurate estimates of soil moisture and projected water needs.

A variety of pilot programs to test moisture sensors are being implemented, such as a program at the Center for Irrigation Technology at Fresno State University, which is evaluating moisture sensors from 11 different manufacturers. The general purpose of such sensors is to evaluate the moisture content of the soil, and to send a signal prohibiting further watering unless the soil needs it. Such sensors can be extremely expensive (on the order of $300 each) making their large-scale distribution unlikely at this time (S. Silva, Metropolitan Water District, personal communication, 1994). The potential savings, however, is extremely large; some manufacturers and independent analysts say up to one-third of the water used for lawn irrigation could be saved (R. Miller, Calsense, personal communication, 1994, E. Norum, consultant to CIT, personal communication, 1994) and enormous additional potential exists in the agricultural sector (see below). Unfortunately, the mere installation of these kinds of sensors is usually insufficient to produce sustainable savings. Training of individuals to maintain and modify their operations under changing conditions is also very important, ruling out extensive use of sensors in the residential market (R. Miller, Calsense, personal communication, 1994). A better set of applications would be in city parks, median strips, and industrial complexes.

Because these sensors and computer controllers represent new technologies and new markets they are not usually produced by large, established manufacturers. Smaller, innovative firms are involved in design and marketing, and these firms are less motivated by tax incentives for research and development and manufacturing; rather they see the need to stimulate the creation of the market by raising rates for water, setting standards, or rebating some fraction of the cost of the product (R. Miller, Calsense, personal communication, 1994). These approaches are discussed later.

3. Agricultural Sector

Agriculture is by far the greatest consumer of water in California and, indeed, in the United States. In many regions, far more water is withdrawn and applied to fields than is actually required to grow crops. This inefficient use of water occurs primarily because the low cost of water provides little incentive for farmers to improve water use efficiency. Associated with this often-inefficient use of water are a large set of secondary issues related to contamination of surface and ground water with agricultural chemicals, adverse impacts on wildlife and ecosystems, and controversies between urban and agricultural water demands.

Several possible futures for the agricultural sector are attainable, with often contradictory implications for present action. One possible long-term goal is to maintain certain agricultural production (such as income levels or crop types or employment levels). Another is to maintain the amount of water consumed while continuing to increase yields and production. A third is to maintain adequate diets for a growing population, which may require ever-increasing amounts of agricultural production. In all such circumstances, water constraints, both in terms of availability and quality will play a role. How do different sustainability goals affect fresh water availability and quality? What incentives are needed to improve irrigation efficiency? How much improvement can we legitimately expect? If the price of water is low, how can investments in new irrigation technology be expected? Without exception, experts on agricultural irrigation efficiency contacted for this report cite the most important incentive to increase efficient water use is to raise the price of water, which for farmers, is almost always subsidized. Yet it was also pointed out that unless agricultural policies permit farmers to move water around, by selling it or leasing it, there is little incentive for farmers to conserve water. Thus, by 2020, substantial agricultural water conservation will likely be the result of higher water rates coupled with the implementation of innovative ways of transferring water.

On-farm irrigation water is useful to farmers only when that water goes to grow crops or to leach unwanted salts from the root zone. Excessive use of irrigation water leads to increased evaporation, unintended percolation to ground water, and unnecessary runoff. Often, excess runoff carries with it agricultural chemicals, such as fertilizer nitrates. While increased irrigation efficiency can reduce water losses and protect and enhance water quality, improvements in efficiency can sometimes lead to lower water quality, or to reduced leaching of salts from soils. The decision about how to best manage irrigation water is thus a complex one, requiring considerable information about the environmental, economic, and productivity implications of different actions.

Improving the efficiency of agricultural water use is already a very high priority in many regions in California and the western U.S. Yet the problem of determining actual irrigation efficiencies and how those efficiencies can be improved is extremely complicated.

Among the factors that must be considered are soil and land characteristics, crop types, irrigation technology, management practices, and agricultural policies and prices.

The major sustainability goal for the agricultural sector adopted by the Institute is to increase, if not maximize, regional agricultural yields (both economic and crop yields) per unit of water consumed without compromising groundwater or surface water quality, or the quantity of water available to maintain natural ecosystems that depend on those water resources. This maximization must take place in the context of explicit goals and resources — farmers will compare the costs of achieving such increases with other economic and social goals.

a) Irrigation Technologies

Many irrigation technologies currently exist on the market. Such technologies include advanced sprinkler systems, drip irrigation systems, agricultural water station networks, real-time moisture monitoring, and central computer controllers. Reducing the cost of laser-leveling, surge valves, and tailwater retention ponds can also reduce water use or improve the quality of irrigation runoff (Pinkham 1994). In addition, while the importance of improving the dissemination of efficient irrigation technology has been acknowledged by many experts, others feel that there is no lack of technology available; rather the impediments to the adoption of new technology are often institutional and educational rather than economics.

This issue became explicit during the June 1994 interim election in California, when an initiative was on the ballot to provide an exemption from property tax reassessment for farmers who install water-efficient irrigation technologies. A remarkably diverse and unusual coalition opposed passage of this initiative, which was defeated by a sizable majority. Environmental groups argued that the proper way to improve irrigation efficiency was to raise the price of water for farmers. Some farm organizations opposed passage on the grounds that many farmers have already installed such equipment and there should be no new tax break for those that had so far failed to do so. Others opposed it on the grounds that the general public would be paying, through a higher tax burden, for a tax break for a small number of farmers (Fresno Bee 1994). This experience suggests that if some sort of financial incentive is deemed necessary, care should be exercised in how to implement it.

b) Land and System Management

Another desirable goal is to take land out of production when that land contributes excessively to poor quality agricultural runoff. Financial incentives for this kind of land management can play a big role in improving overall water quality at a modest cost. At present, there are several programs to purchase and retire poor quality agricultural lands by state and federal governments. California is implementing a bill to finance land retirement, and the new Central Valley Project Improvement Act permits the Secretary of the Interior to use land retirement as means of acquiring water supplies (C. Congdon, Environmental Defense Fund, personal communication, 1994).

Interviews with several irrigation districts and farming representatives suggest that system management is very important, including changes in irrigation timing, mode of operation, and system design. New ways of controlling irrigation systems (such as software programs, computer controllers, and more accurate monitoring) are increasingly available, but not yet well implemented.

c) Reducing Delivery Losses

In some regions, substantial quantities of agricultural water are lost between its source and the point of final use, through seepage from unlined irrigation canals to evaporation from the surface of aqueducts and reservoirs. When water from agricultural delivery systems seeps into a groundwater aquifer used by other farmers, it is often possible to recapture the water through groundwater pumping. True losses occur only when water is evaporated away or seepage is chemically contaminated or lost to a saline sink. Monitoring and measuring real losses are hard to do, but preventing the losses is not — canals can be lined with an impervious material and pipes maintained, if the cost of doing so is below the cost of finding equivalent amounts of new water. Recently, third parties, mostly urban water utilities, have begun to approach irrigation water districts to offer to participate in capturing some of this lost water. In return for all or some of the water "saved," the third party covers the cost of lining the canal and transporting the water. These actions are often extremely cost-effective ways of increasing overall water availability. Secondary issues, however, arise when the water that traditionally seeped out of the canals is subsequently used by other users. For example, the Metropolitan Water District of southern California has recently offered to pay for lining the All-American Canal along the U.S./Mexico border in return for the water "saved" by eliminating seepage. Approximately 100,000 acre-feet of water are estimated to be lost in this fashion. In fact, one user's loss is often another user's gain. In this case, Mexican agriculture in the Mexicali Valley pumps approximately this amount of water directly attributable to seepage loss from the canal and claims that the U.S. cannot line the canal without consultation with Mexico (Hayes 1991). This dispute is currently unresolved.

Unlined irrigation canal in the North Sacramento Valley. (Photo: P. Gleick)

B. ECONOMIC MECHANISMS

Moving toward more efficient, ecologically sound, and sustainable patterns of water use requires major changes in the way water is valued, allocated, and managed. Central to the effort to revamp the way California manages its water resources will be pricing policies that reflect the costs of water to particular users at particular times of use. Historically, water prices have not fully reflected the costs, both social (environmental degradation associated with water development) and capital (opportunity costs of plant and equipment), of providing water to users.

1. Rate and Pricing Policies

Some water utilities are now seeking ways to modify their rates and exploring alternative pricing structures to help ensure more productive and efficient use of water (Morris 1990). Through such policies they hope to delay the need for additional water supplies, avoid all or part of the estimated $6 to $7 billion in improvements to comply with the Safe Drinking Water Act, and reduce the cost of treating wastewater to comply with Clean Water Act standards (Curry 1994).

Many possible rate structures could be implemented. Figure 12 shows some of the common urban rate structures. Already, two rate structures — *seasonal* and *increasing-block or tiered-block rates* — are being used to encourage conservation in areas that have chronic water shortages or limited capacity. *Seasonal rates* are implemented for water consumed during a utility's peak-use season, either as a means of recovering the incremental cost of providing water or as an inducement to conserve water because of inadequate or constrained supply. *Increasing-block rates* use two or more rate blocks with increasing unit rates as consumption increases.

It is common practice to apply tiered-block rates separately to residential and nonresidential customers because of the large differences in water use. The separate rate schedules for each class can encourage large-volume customers within each class to reduce usage. For example, according to the DWR, increasing-block rates work well with large water users (commercial, industrial, and governmental) only if the differences between the blocks are significant (Curry 1994).

In the residential sector, significant and permanent savings result when water rates are combined with indoor and outdoor fixture replacement programs, water audits, and landscaping ordinances. For large industrial, commercial, and governmental customers, monetary rebates (as a reward for conserving water) coupled with higher rates can produce significant water savings.

That rates influence demand for water has been shown repeatedly by empirical research. The measure of this relationship between the price of water and its use is called the *price elasticity* of demand, which gauges the expected response in demand given a change in price. The water utility industry had for a long

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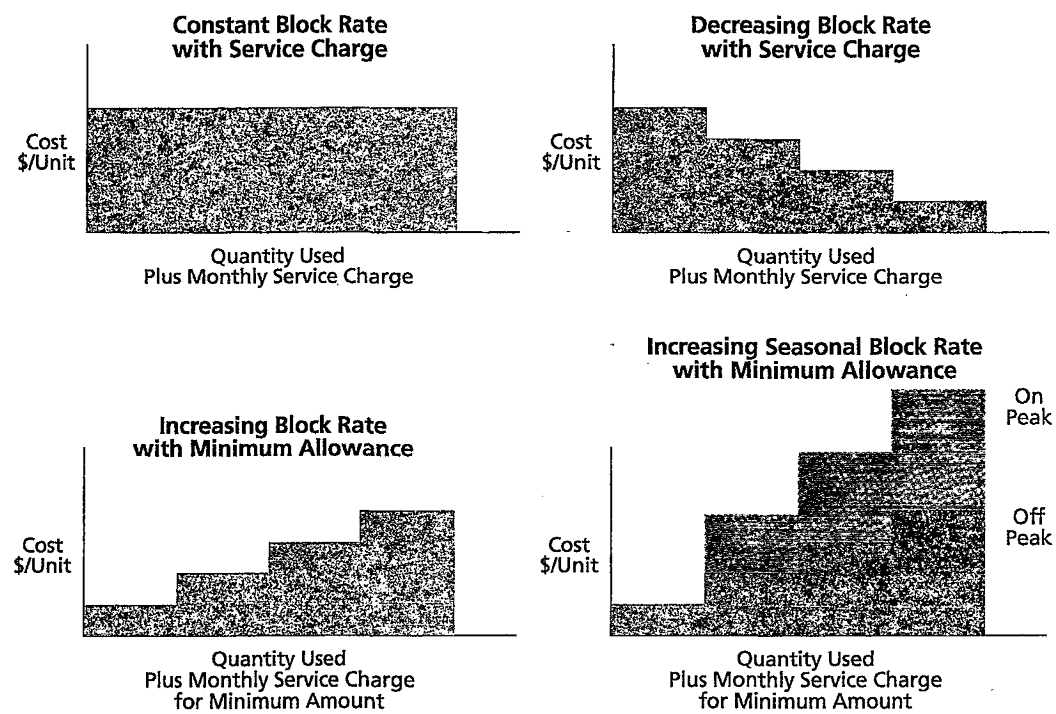
Figure 12
Urban Water Rate Structures



Source: Modified from DWR 1994a.

time assumed implicitly that the price elasticity of demand for water by residential customers was zero, i.e., higher prices have no effect on quantities demanded. However, numerous recent studies show that it can be as high as 50 percent (see, for example, Dziegielewski et al. 1991). Table 26, below, summarizes some of these recent findings.

The price elasticity figures in Table 26 can be interpreted in the following way: a 10 percent increase in the price of water would result in decline in single-family residential water demand of 1 to 3 percent during the winter and 2 to 5 percent during the summer. Similarly, one might expect demand by multi-family residential customers to decline by 0 to 1.5 percent in the winter and 1/2 to 2 percent in the summer. This simple illustration shows that demand is more elastic in the summer season than in the winter season (off-peak season).

Results from other empirical studies also show that *outdoor water use is more responsive to price than indoor use*, especially in the summer months when outdoor use is greatest. Because outdoor use tends to be much more discretionary than indoor water use, people are more able and/or willing to adjust outdoor water use as prices change. Because outdoor water use occurs mainly in the "peak" summer months, the cost of providing water to satisfy "peak" outdoor demand is higher than during other periods. For this reason, outdoor use should be priced at a higher rate during "peak" periods of the year, either as a means of recovering the incremental cost of providing water during peak periods or as an inducement to conserve water because of seasonally limited supplies.

Elasticity of demand also varies depending on whether it is viewed in the short- or long-run. While price is less effective in changing residential water use in the short-run, it plays

Table 26
Price Elasticity Estimates for Residential Water Use

Single-family Residential Customers	Range of Elasticities		
Winter season	-0.10	to	-0.30
Summer season	-0.20	to	-0.50
Multi-family Residential Customers			
Winter season	0.00	to	-0.15
Summer season	-0.05	to	-0.20

Source: Mitchell and Hanemann 1994.

an important role in guiding long-run water use decisions. A Tucson, Arizona study that examined residential water demand between 1974 and 1980 found long-run elasticity of demand to be nearly twice that of the short-run (Mitchell and Hanemann 1994).

Evidence suggests that water is chronically overused because it is consistently underpriced.

All of this evidence suggests that water is chronically overused because it is consistently underpriced. With demand for urban water continuing to outpace supply, urban water agencies face a new reality where providing a reliable, affordable service will depend as much on how they manage demand as on how they manage supply. Innovative ways to price water services to encourage more efficient use, and adaptation of cost-effective conservation, efficiency, reuse, and recycling measures will be key to meeting tomorrow's needs.

2. Ratebase Water Conservation and Efficiency

Permitting regulated water agencies to put expenses for conservation and efficiency programs into their ratebase, as occurred in the energy industry in the late 1980s, would go a long way toward putting these programs on the same footing as new supply projects. Under current policies, water utilities are, for the most part, unable to receive a return on investments in water conservation and efficiency programs, unlike investments in new supply projects. Absent policies that place conservation and efficiency on the same footing as new supply projects, such strategies will continue to be viewed only as emergency drought response options.

3. Agricultural Water Policies

There are several different actions that local water agencies can take to restructure the way that farmers use water (see Table 27). In the short-term, districts can implement increased block rates, ration allocations, move allocations from one farmer to another, negotiate inter-district transfers, improve management of deliveries, increase groundwater use, change the use of existing surface storage, and implement information sharing and education on conservation techniques among its members. In the longer-run, districts can improve delivery-system efficiency, increase storage capacity and groundwater pumping capacity, negotiate long-term transfers, renegotiate water contracts with state and federal agencies, and implement better planning and monitoring.

The state and federal agencies responsible for operating the SWP, CVP, and other supply projects also play a role in agriculture's use of water. On a short-term basis, these agencies can improve management of deliveries, facilitate inter-district short-term transfer markets, and provide assistance with conservation for districts and individual producers. In the long term, changes in public policy and planning can also have important effects. For example, the CVPIA requires the re-allocation of 800,000 af to environmental uses. Federal commodity programs also influence the types and quantity of crops planted, crop prices, and ultimate water demand. Zilberman et al. (1993) found that about 40 percent of California crop acreage is under some federal or state price and income support program. The state can also implement statewide groundwater regulation or facilitate local groundwater management. Finally, statewide planning can better coordinate the various uses of water to ensure that the sustainability criteria are being met.

Many other important factors influence the producer's choice of what crops to grow, how much to grow, and how much water to apply. For example, trends in global commodity markets such as the North American Free Trade Agreement and the General Agreement on Tariffs and Trade affect crop prices. The financial condition of farms is also important since generally only financially sound farms can undertake large capital investments in efficiency equipment.

4. Lessons from San Joaquin Drainage Areas

The experience of several districts on the west-side San Joaquin Valley shows the tremendous flexibility of agriculture to adapt to changing conditions. Through district-level conservation programs and tiered pricing San Joaquin Valley west-side farmers increased irrigation efficiency and reduced drainage water in an effort to

Table 27
Possible Responses to Water Cutbacks in the Agricultural Sector

Level of Response	Short-term (same year as cutback)	Long-term (3 or more years)
Farm	• Fallow crop land • Improve irrigation scheduling • Increase groundwater pumping • Buy or sell water via transfers within district or between districts • Water-stress crops • Switch type and amount of crops planted	• Change total size of farm operation • Change crop types and rotations • Invest in more efficient irrigation technology • Increase on-farm water storage • Increase groundwater pumping capacity • Leave farming or relocate
District	• Restructure water rates • Ration supply • Buy water from other districts • Increase groundwater pumping • Initiate intra-district water trading • Improve operations and management of water deliveries • Implement educational and technical assistance programs for farmers	• Improve delivery system efficiency • Increase storage capacity • Increase groundwater pumping capacity • Negotiate long-term water transfers • Renegotiate state and federal contracts • Build planning and management infrastructure • Implement conjunctive use programs for ground and surface water
State and Federal	• Set up interdistrict short-term transfers • Improve delivery efficiency • Provide conservation assistance	• Restructure agricultural commodity subsidies • Renegotiate water contracts • Build planning and management infrastructure

reduce some of the severe drainage problems there.

The Broadview Water District implemented a tiered pricing rate structure in 1988. This small district of 10,000 acres next to the Westland Water District grows primarily cotton, melons, wheat, alfalfa seed, and tomatoes. They were faced with the problem of having to reduce the volume of contaminated drainage water flowing into the San Joaquin River. An increasing block rate for water use was seen as one way to help achieve drainage reductions and a program to implement such a structure was developed. The rate was set at $16 per acre-foot for the first 90 percent of the 1986 to 1988 applied water average and $40 per acre-foot for any additional water. Accounting for water was fairly accurate because of careful monitoring.

By 1991, only seven of 47 fields exceeded the tier levels (see Table 28). The district average applied water decreased 19 percent, from 2.81 acre-feet/acre for 1986-88 to 2.27 acre-feet/acre in 1991. During this same period melons, wheat, and alfalfa seed crop production decreased, but there was an increase in tomatoes harvested (MacDougall et al. 1992). Drainage was both reduced substantially and smoothed out over the season. The drainage volume decreased from an average of 3,521 af per year over 1986-88 to 2,665 in 1990; salt discharges decreased from 26,000 tons to under 22,000; and boron decreased from 30.3 tons to 26.2 tons (Wichelns and Cone 1992). In addition to the rate changes, discussions and workshops with farmers facilitated the exchange of information, contributing greatly to the success of the program (Wichelns and Cone 1992).

A review of water conservation experiences in irrigation districts concluded that accurate measurement and comprehensive metering are essential for efficient water management (Thomas et al. 1990). If all districts in the San Joaquin Valley achieve the level of efficiency of applied water achieved by the most efficient districts, then according to 1984 data, more than 671,000 af are potentially available for reallocation from the San Joaquin Valley alone.

While local experiences cannot be easily generalized to the state as a whole, they do point to promising areas for adapting to water cutbacks. The distinction between savings in applied water and savings in consumed water should be kept clear. Increased irrigation efficiency can lower applied water requirements, but actual water consumed may not change unless the crop evapotranspiration requirements change by either growing different crops or fallowing land.

Table 28

Broadview Water District's Tiered Water Pricing Experience[a]

Crop	1986-88 average	1989	1990	1991	Percentage Change (86-88 to 91)
Acres					
Cotton	4,100	4,649	4,416	3,828	-6.6%
Melons	1,095	1,279	814	198	-81.9%
Wheat	939	708	903	304	-67.6%
Alfalfa Seed	813	694	549	456	-43.9%
Tomatoes	627	840	850	662	5.6%
Total	7,574	8,170	7,532	5,448	-28.1%
Acre-feet per acre					
Cotton	3.20	3.34	2.84	2.40	-25.0%
Melons	2.11	1.93	1.79	1.46	-30.8%
Wheat	2.30	3.02	2.18	1.60	-30.4%
Alfalfa Seed	2.06	1.84	1.88	1.36	-34.0%
Tomatoes	3.22	2.72	3.03	2.69	-16.5%
Weighted Average	2.81	2.90	2.60	2.27	-19.2%
Total acre-feet applied					
Cotton	13,120	15,528	12,541	9,187	-30.0%
Melons	2,310	2,468	1,457	289	-87.5%
Wheat	2,160	2,138	1,969	486	-77.5%
Alfalfa Seed	1,675	1,277	1,032	620	-63.0%
Tomatoes	2,019	2,285	2,576	1,781	-11.8%
Total	21,284	23,696	19,575	12,364	-41.9%

Source: Broadview Water District 1992 Drainage Operation Plan as cited in MacDougall et al. 1992.

[a] *Tiered pricing adopted in 1988. Farmers paid $16 per acre-foot for all water applied below the tiering levels shown below and $40 per acre-foot for water applied above these levels.*

	Acre-feet per acre
Cotton	2.90
Melons	2.11
Wheat	1.90
Alfalfa Seed	1.90
Tomatoes	2.90

C. INFORMATION AND EDUCATION APPROACHES

Information and education are crucial components of any successful water management and planning programs. The recent droughts in California provide numerous examples where voluntary efforts to reduce water use were successful because of the effective dissemination of information (DWR 1993a).

If water utilities, irrigation districts, or state and federal water purveyors want to promote or require conservation among their customers, they need to understand how these customers use water; that is, they need to answer the question "How is water used?" To understand how customers use water, the water utilities need to conduct customer surveys and audits. They then need to use the information from the customer surveys and audits to persuade the customers to change their usual way of operation. Water use varies depending on the type of customer, facility or business, climate, and many other variables. For this reason, appropriate methods of reaching each type of customer will vary.

The need to use water more efficiently also must be effectively communicated to the water users. This will require aggressive media campaigns and dissemination of information (describing current and future water conditions). In addition, water agencies in cooperation with electric utilities and government need to successfully address issues such as:

- the cost effectiveness of conservation or efficiency measures (i.e., customers must be given good reason to change);
- the direct and indirect effect of the measure on profits;
- the availability of financing, which is especially important when the customer's budget does not include funds to cover the initial capital cost of plant improvement projects. This is also extremely important for low-income households that cannot afford capital outlays for new fixtures or appliances;
- the need to convince businesses and facilities about the accuracy of the information on which the recommendations are based; and
- the need to publicly recognize companies that are water efficient.

1. Audits

A major barrier to efficient water use is the lack of information about the role of behavior, and the availability and cost of water-efficient technologies. Such information can be provided in many ways, including educational programs and "informational incentives," defined by the California Urban Water Agencies as "the provision of information for which customers would otherwise have to pay" (Barakat and Chamberlin 1994). Evidence suggests that site-specific information on current water use is extremely effective at influencing customer behavior and the adoption of conservation technologies.

Audits typically have two components: (1) a detailed site-specific survey of current water uses and needs; and (2) provision of site-specific information on alternative, more efficient technologies and practices. Such audits are typically conducted either by the local water utility or by a commercial operation. In the former case, the cost is typically borne by the utility. In the latter case, the cost of the audit is often offset by some agreement to share the savings that accrue from implementing the suggested changes. For both cases, identifying ways to reduce the price or cost of audits would increase their likelihood of being undertaken.

Audits of water use have the potential to identify substantial savings of water in almost all sectors. Financial incentives to get utilities or private contractors to offer audits could be extremely valuable, but almost all studies done of audits emphasize that they need to be combined with programs to ensure that identified savings are actually attained, by getting customers to implement, and maintain, the proposed changes. Mechanisms to encourage the adoption of the recommended changes are discussed later.

a) Residential Audits

Residential audits provide residential customers with indoor and outdoor evaluations of water use and needs. Audits are conducted by either trained utility staff or outside contractors. Some audits specifically involve direct installation of conservation devices, while others are purely informational. Some training is required for auditors, and the cost of a typical

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residential audit is about $45 to $75 when an audit of outside water use is included (Barakat and Chamberlin 1994).

b) Industrial Audits

Industrial audits are highly site specific and far more difficult to do than residential audits, given the often highly complex nature of industrial practices. These audits include detailed assessments of how and why water is used in a facility and may require temporary monitoring at a variety of points in a process, evaluating the heating, ventilation, and air-conditioning systems, and testing of water-using equipment. The cost of industrial water audits depends on a wide range of factors, including the type of process, the services provided, and the extent of the audit. The Metropolitan Water District of Southern California estimates its industrial water-management studies cost $5,000 to $15,000, based on what their customers would have to pay for comparable audits by the private sector. Because of the expense and difficulty of such audits, few water agencies offer them, although estimates of possible water savings in audited industries range as high as 30 to 40 percent (Brown and Caldwell Consultants 1990).

c) Commercial and Institutional Audits

Commercial and institutional activities can also benefit from detailed water-use audits, which can include all the components of a residential audit (indoor fixtures, outdoor turf irrigation) as well as reviews of heating, ventilation, and air-conditioning systems. Institutional energy and water audits of all federal facilities are supported by the Energy Policy Act of 1992, which requires implementation of efficiency measures with a payback period of ten years or less. Commercial and institutional audits are typically less complicated and less expensive than industrial audits and may focus on high-volume, peak-period users or on customers with single-pass cooling systems or large areas of outdoor turf irrigation.

d) Large Landscape Audits

Some municipal, institutional, or industrial customers maintain large landscapes (such as lawns) requiring irrigation. These landscapes are often large consumers of water. Landscape audits typically cost about $200 per acre and require outside expertise or training.

2. Other Training Programs.

Another educational activity to help water consumers take conservation actions or to implement conservation measures is a training program or workshop. Such courses can be offered or sponsored by the water utility for specific groups of customers or for particular kinds of technologies or practices, such as landscape irrigation. Incentives to offer, or to take, such workshops can improve the success of conservation programs in a wide range of sectors. Agricultural training is often available through extension services and other state or university programs. More effort is needed to get information on water issues into these programs.

D. REGULATORY APPROACHES

Since educational and economic incentive programs will not motivate everyone to conserve, regulatory approaches must also be evaluated and considered. Legislation setting standards has been used for many purposes, such as saving energy, ensuring safety, protecting human health, and preventing environmental degradation. Recently, there have been some modest efforts to set standards for water-using technologies and behaviors. Setting water-efficiency standards for common fixtures – such as toilets, showerheads, and faucets – can be a critical component of a permanent and reliable water conservation strategy. Legislation and regulation at the local, state, and federal levels are playing an increasing role in establishing water conservation requirements for water utilities and the public. Standards establish technological norms that ensure a certain level of efficiency is built into new products and services. As the stock of water fixtures is replaced with more efficient fixtures, there will be continuing permanent reductions in water demand. Other approaches, such as landscape ordinances aimed at societal preferences, can also be used to alter water-use patterns.

1. Technology Standards

A variety of technology-based standards are being used to reduce water demand. For example, following the severe drought of 1976-77, state law in California required more efficient toilets (3.5 gallon-per-flush) in all new construction. On a more local level, several communities including Los Angeles, Petaluma, Santa Monica, and Sebastopol, have passed ordinances requiring the use of high-efficiency water fixtures in all new construction, remodeling, and additions. More recently, the 1992 National Energy Policy Act (NEPAct) established national standards for toilets, urinals, showerheads, and faucets. The efficiency standards are shown in Figure 13 below and took effect January 1, 1994. As pre-1994 fixtures are replaced with more efficient fixtures as required by the NEPAct, per-capita water use is expected to drop substantially.

The NEPAct has three basic water components: the establishment of maximum-water-use (efficiency) standards for plumbing fixtures, product marking and labeling, and recommendations for state and local incentive programs to accelerate voluntary fixture replacement. Studies of the NEPAct's impact on domestic water use show that they will be substantial. Replacing an existing 5 to 7 gallon-per-flush toilet with a 1.6 gallon-per-flush toilet will, by itself, save up to 20 percent of total indoor water use for a family of four. One study concluded that the introduction of these efficiency standards will reduce residential water use for toilets, showerheads, and faucets by 62 percent when replacing pre-1980 fixtures and 39 percent when replacing fixtures installed between 1980 and 1993 (Vickers 1993).[14] Based on our analysis, we estimate that the NEPAct water-efficiency standards will reduce residential water use for toilets, faucets, and showerheads by approximately 57 percent for pre-1980 and post-1980 fixtures combined. That the standards will have substantial impacts even in communities with robust water conservation programs is unquestionable.

The passage of the NEPAct will not only influence water demand, but also the volume of wastewater generated over the next several decades. Yet little discussion about the potential impacts of the NEPAct water-efficiency standards has occurred at the state level. For example, DWR's Bulletin 160-93 and Bulletin 166-4 failed to incorporate its requirements into their analysis (DWR 1993, 1994a, 1994b). At the utility level, the expected demand reductions will influence important policy and planning decisions, but few utilities have yet to estimate their impacts.

a) Housing and Landscape Ordinances

Better land-use policies, including landscaping ordinances and other regulatory measures to promote multi-family housing should be explored. Because multi-family structures share landscapes or have significantly smaller landscapes, and generally have fewer water-using appliances, average per-capita water use is lower than in detached single-family residences. A 1985 study conducted by the Planning and Management Consultants for the Metropolitan Water District concluded that the average annual single-family water use was 384 gallons per day, 128 gallons more than the average multi-family home (see Table 29 below). The study concluded that a person residing in single-family home used 140 gallons per day, or 46 gallons more than someone residing in a multi-family residence (Dziegielewski et al. 1991). Outdoor water use

Table 29
Estimates of Average Annual Water Use in Southern California

Residential Sector	Gallons per dwelling per day	Gallons per person per day
Single-family	384	140
Multi-family	256	94
All residential	327	119

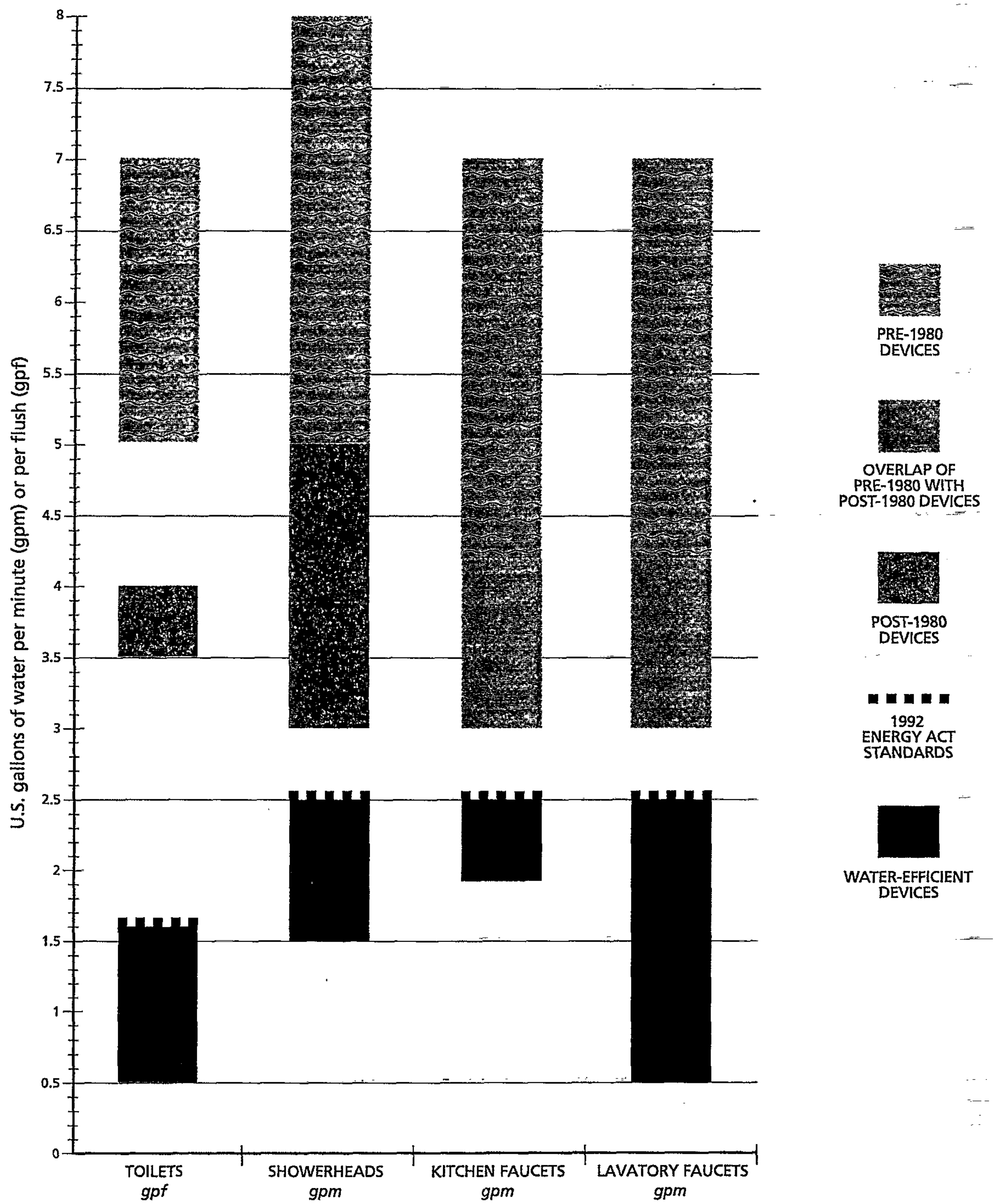
Source: Dziegielewski 1991.

[14] These estimates are consistent with the 57% potential savings estimates for faucets, showerheads, and toilets we calculated for existing California equipment.

Figure 13

Water Used by U.S. Faucets, Showerheads, and Toilets

A comparison of the approximate range of water used by pre-1980 devices, post-1980 devices, and water-efficient technologies.



Source: Modified from Rocky Mountain Institute 1991.

in multi-family dwellings was less than 18 percent of total household use, compared to 35 percent in single-family units (Dziegielewski et al. 1991). An increase in the share of multi-family housing, as a percentage of total housing stock, would result in substantial water savings statewide. Such a trend was evident in California between 1970 and 1980, but appears to have leveled off during the 1980s (see Table 30).

Landscape water-conservation ordinances that limit turf size, require xeriscape landscaping, and/or improve management practices can also produce substantial outdoor water savings. Because of the multitude of factors involved, such ordinances should be enacted at the local level, preferably by the local water agency. However, if the water agency does not have the authority to enact ordinances, it should work with cities, counties, the state, and green industry in the service area to develop and implement landscape water-conservation ordinances. A structure for doing this has already been developed by the Water Conservation Landscaping Act of 1991 (California Government Code sections 65590 *et seq.*). This Act required that by January 1, 1993 all cities and counties in California either adopt the Model Ordinance (the Model Water Efficient Landscape Ordinance was adopted in August 1992 and is codified in Title 23 of the California Code of Regulations sections 490-92) or issue findings that they do not need such an ordinance.

If the city or county did nothing, then the state's model ordinance would automatically go into effect. Because of the Landscaping Act, many cities got serious about outdoor water conservation. Contra Costa County, for example, now limits turf to 20 percent of landscape area in some home developments.

Xeriscaping shows the greatest promise of creating sustainable and reliable outdoor water savings. A study conducted by North Marin Water District found that landscapes with about half as much lawn as traditional yards required 54 percent less water, 25 percent less labor, 61 percent less fertilizer, and 22 percent less herbicide (RMI 1991).[15] Similarly, an East Bay Municipal Utility District study of single-family houses comparing daily water consumption with water-conserving landscapes against traditional turf-oriented landscapes estimated residential water savings at 42 percent (RMI 1991).

Table 30
Percentage of Single- and Multi-Family Households in California

	1970	1980	1990
Single-Family	76%	63%	63%
Multi-Family	24%	37%	37%
Total	100%	100%	100%

Source: DWR 1994b.

b) Best Management Practices (BMPs)

The California Urban Management Council has developed the *Memorandum of Understanding Regarding Urban Water Conservation in California*. As of June 1994, there were 170 signatories to the Memorandum of Understanding (MOU), including 111 water agencies and 59 public interest groups. The MOU contains 16 best management practices that address interior and exterior water use.

Best Management Practices

- Interior and exterior water audits and incentive programs for single family residential, multifamily residential, and governmental/institutional customers
- Plumbing, New and Retrofit
- Distribution system water audits, leak detection, and repair
- Metering with commodity rates for all new connections and retrofitting existing connections
- Large landscape water audits and incentives
- Landscape water conservation requirements for new and existing commercial, industrial, institutional, governmental and multifamily developments
- Public information
- School education

[15] The seven principles of xeriscaping are: good planning and design, limited turf areas, efficient irrigation, soil improvements, mulches, low-water use plants, and appropriate maintenance (RMI 1991).

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- Commercial and industrial water conservation
- New commercial and industrial water use review
- Conservation pricing
- Landscape water conservation for new and existing single family homes
- Water waste prohibition
- Water conservation coordination
- Financial incentives
- Ultra-low flush toilet replacement programs

In addition to the BMPs that water utilities have committed to implement, the following are potential BMPs that can and should be implemented:

- Rate structure and other economic incentives and disincentives to encourage water conservation
- Efficiency standards for water using appliances and irrigation devices
- Replacement of existing water using appliances (except toilets and showerheads whose replacements are incorporated in BMPs) and irrigation devices
- Retrofit of existing car washes
- Gray water use
- Distribution system pressure regulation
- Water supplier billing records broken down by customer class (e.g., residential, commercial, industrial)
- Swimming pool and spa conservation including covers to reduce evaporation
- Restrictions or prohibition on devices that use evaporation to cool exterior spaces
- Point-of-use water heaters, recirculating hot water systems, and hot water pipe insulation
- Efficiency standards for new industrial and commercial processes

The MOU is voluntary and leaves it up to the participating utility to decide what BMPs it will or will not implement. That is, although a measure is listed as a BMP, a water district is not required to carry it out if it is deemed technically infeasible, socially unacceptable, or economically unjustified for that area (Vickers 1991). While giving districts the flexibility to not implement measures that are "technically infeasible" and "economically unjustified" is reasonable, it may not be reasonable to permit them to refuse to implement programs that are only "socially unacceptable." For this reason, the state should consider requiring all water utilities to implement BMPs that are "technically feasible" and "economically justified" regardless of their "social acceptability." Other mechanisms to ensure implementation of urban BMPs should also be explored.

E. TECHNOLOGIES AND PRACTICES TO INCREASE SUPPLIES

While the overall quantity of fresh water resources is fixed, there are technologies and practices that can be adopted that increase water availability on a regional or seasonal basis. For example, dams have traditionally been built in part to capture water during wet periods for use during later dry periods. Aqueducts and pipelines move water from areas of water surplus to areas of high demand. And technologies that permit water reuse can effectively reduce demand for new water by increasing the number of times the same quantity of water can be used. The following sections describe the advantages and disadvantages of an untraditional set of technologies and practices that are likely to be considered in the next few decades. This set of alternatives has been chosen to be consistent with the sustainability criteria developed earlier.

1. Wastewater Treatment and Use

There is broad agreement that reclaimed wastewater is a resource that can meet many existing water requirements. There is less agreement about how to encourage the use of this resource and about the extent to which wastewater can be used. By far, the most important first step to encouraging the use of wastewater is to do a comprehensive assessment of the likely uses for wastewater, the quality of water required to meet those needs, the availability of wastewater as a function of quality, and the relative costs of treating and delivering this resource. Some work in this area is already underway, such as the activities of the Central California Regional Water Recycling Project, which is evaluating the potential of using more than 200,000 acre-feet per year by 2010, on top of existing wastewater use activities in the San Francisco Bay Area and surrounding areas.

Southern California has comparable planning activities underway, in large part because for some southern California municipalities, the costs of delivering reclaimed water are far below the costs of delivering State Water Project supplies over the Tehachappi Mountains. Several cities, such as San Diego, have adopted ordinances that encourage or require the use of reclaimed water wherever feasible and wherever beneficial to public health, safety, and the environment (San Diego Ordinance 0-17327, July 24, 1989). Such ordinances should expedite the use of reclaimed water.

Increasing the use of recycled water from either waste-treatment plants or from water recovered from industrial processes can reduce the need for potable water. This is particularly true for large industrial users. Refineries, for example, are significant users of water, and increasing their use of reclaimed water can greatly reduce overall water demand in certain water districts. There is no requirement that potable water be used in cooling towers, but the use of reclaimed water for cooling may require replumbing. Financial incentives to promote such replumbing may be necessary. The Chevron Richmond Refinery in northern California currently uses just under 11 million gallons of water per day, half of which is lost to evaporation from cooling towers. At present, all of this water is drinking water supplied by the East Bay Municipal Utilities District (EBMUD). EBMUD and Chevron have developed a plan, however, in which all of this cooling water will be replaced with municipal reclamation water by 1996, effectively reducing the consumptive use of potable water by the refinery by 50 percent (P. Yolles, Pacific Institute, field visit, 1994).

In Los Angeles, a new water recycling facility, the Hyperion Plant in the Western Central Basin, will produce 70 million gallons per day of tertiary treated water. A secondary pipeline system, to permit the use of this water, is now being built, and the water from this system is being artificially priced at 80 percent of the price of potable water in order to stimulate the market for its use.

2. Graywater and Rainwater Use

The use of graywater and rainwater collection systems can dramatically reduce overall potable water needs. Graywater systems collect water from sinks, washing machines, and showers, filter it, and store it for use in toilets, urinals, or most typically, lawn irrigation. There are few commercially manufactured graywater systems in the U.S., but the Office of Water Reclamation in Los Angeles estimates that individual homes with such systems can reduce overall water consumption by 50 percent (RMI 1993).

Similarly, rainwater collection systems in some regions can provide substantial portions of all non-potable residential water needs. Once common in the U.S., rainwater collections systems can also reduce total water flows to wastewater systems, reducing the need for new systems or the load on existing systems. On the island of Hawaii, local government has developed guidelines to help residents build safe catchment and storage systems, and 25,000 people are estimated to rely on rainwater for their entire water supply (Chapin 1994).

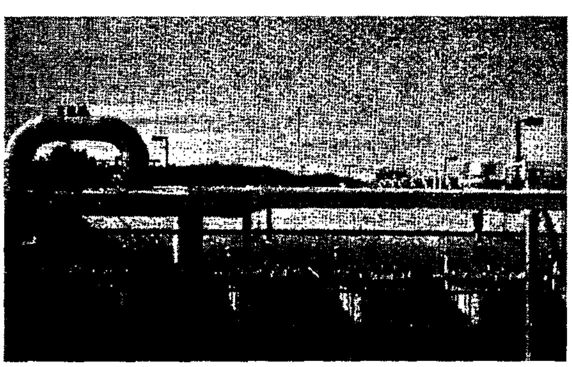
A major barrier to the widespread adoption of both graywater and rainwater systems is the resistance often encountered when there is a fundamental change in the system with which people are familiar. Such changes can be brought about, but often require long periods of time.

3. Alternative Treatment Systems

Substantial expenses are incurred by communities and municipalities for wastewater treatment facilities. Current provisions of the Clean Water Act are quite specific about the standards and technologies required for treating water, and these facilities are often extremely expensive to build and operate. Many of the water-efficient technologies discussed above contribute to reducing the cost of wastewater treatment by reducing the overall volume of water requiring treatment, which either decreases the size of facilities required or delays the need for new facilities. A different approach, however, is to use alternative technologies for treating wastewater, such as using the abilities of wetlands and marshes to clean up certain kinds of wastewater using natural processes.

At the moment, several innovative groups are doing research into these technologies, which can offer several advantages, including reduced energy costs, lower land requirements, and the ability to address sewage problems at a smaller scale than typical conventional secondary treatment systems. Some of the groups claim that their systems can provide tertiary quality treatment for roughly the same price as conventional secondary treatment systems (S. Sargert, Ocean Arks, personal communication, 1994). Ocean Arks, a company in the northeast, designs, builds, and operates smaller-scale waste-treatment facilities with a focus on using the biological advantages of wetlands/marsh systems. They are operating a 30-40,000 gallon per day system in Frederick County, Maryland to treat residential sewage and a test facility in Toronto to treat wastewater from a distribution warehouse for the Body Shop. They are also designing facilities for the state of Vermont to treat 100,000 gallons per day and for the city of San Francisco for treating storm water runoff.

A niche where such alternative facilities could be extremely useful is where septic tanks are in disfavor and where residential communities are trying to protect ground water. At present, 30 percent of the U.S. population is not served by sewers and depends on septic tank/leach field technology. Most small communities are unable for technological and economic reasons to build major waste-treatment facilities, making these kinds of smaller unconventional systems particularly attractive. Among the needs to expand the field are further technical demonstrations, some financial incentives to permit communities to consider non-traditional approaches, and removal of restrictions in current legislation on the kinds of facilities built. In particular, opening up the provisions of the Clean Water Act to permit innovative systems to compete is urgently needed. To upgrade systems from septic tanks to some alternative system, or from secondary to tertiary treatment may require tax credits or low-interest loans to individuals, companies, and communities (S. Sargert, Ocean Arks, personal communication, 1994).



A major, and expensive, desalination plant was built in Santa Barbara following the drought of the late 1980s and early 1990s. (Courtesy of DWR.)

4. New Supply

Given the large potential for increased water-use efficiency in all sectors, we are reluctant to recommend here incentives for new supply options that move water from water-rich to water-poor regions, or that require the construction of large new water-storage facilities, particularly in the western United States. Such traditional approaches have entailed enormous environmental and economic costs, and the realization of these costs is a major impediment to the construction of any new facilities. One possibility stands out, however, that meets our sustainability criteria: the use of saltwater or brackish water desalination *when that desalination is accomplished with renewable energy.*

By far the vast majority of global desalination technology today relies on fossil-fuel generated electricity or heat. As of early 1991, few solar-powered desalination facilities had been constructed due to their higher costs. While this option is economically infeasible today, the costs of photovoltaics have been dropping continuously and significantly for several years, and the next 25 years are likely to bring some dramatic changes. Solar desalination may become an attractive way to supplement fresh water availability, especially in remote or arid regions with few alternatives (Gleick 1993).

Another unusual possibility is water transportation from out-of-state sources through non-structural means, such as "bag" technology currently under development. Water has long been shipped in emergency situations via tanker from one region to another. In 1994, for example, substantial amounts of water were brought to Japan by tanker to mitigate the impacts of a severe drought there (U.S. Water News 1994b). The problem with tankers is their relatively low volume and the relatively high cost of transportation. In 1995, at least three independent companies are exploring the use of large synthetic bags for transporting water around the world. These bags could be linked together to form "trains" and towed through the oceans to the point of need. As of mid - 1995, the technological feasibility of such an approach has not been proven, though demonstrations by some of these innovators appear imminent. Ultimately, their utility will depend on the economics of the method and the politics of finding reliable water suppliers willing to ship water to other regions.

VII. Conclusions and Recommendations

"It is hereby declared that because of the conditions prevailing in this State the general welfare requires that... the waste or unreasonable use or unreasonable method of use of water be prevented, and that the conservation of such waters is to be exercised with a view to the reasonable and beneficial use thereof in the interest of the people and for the public welfare." —Article X of the Constitution of the State of California.

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 the traditional water policies that helped California become the agricultural and economic force it is today are not up to the task of meeting the challenges of the 21st century. Yet the very groups responsible for preparing the state for the coming challenges are mired in the policies of the past. For the past year, the Pacific Institute has been exploring alternative paths into the next century in the hopes of trying to provide new insight into appropriate water policies. This report takes a unique look at how the state might begin to plan for a truly sustainable water future, presents a positive vision of what that future might look like, and discusses how such a vision might be achieved.

A. THE PROBLEM

California's current patterns of water use are unsustainable. Groundwater use is unmonitored and uncontrolled and in many places groundwater is being used at rates faster than it is being replenished. Ever increasing amounts of water are required to meet urban demands, adding to the conflict among agricultural, urban, and environmental interests. Urban water use is inefficient and poorly managed. Environmental water needs are poorly understood and rarely met. Fish and wildlife species are being driven to extinction and habitats are being destroyed by development. And official projections are that such problems will continue indefinitely.

According to the California Department of Water Resources, California water policies — and problems — in the year 2020 will be little changed from today. The state will grow the same kinds of crops, on about the same amount of land. Rapidly growing urban populations will still use water inefficiently, wasting large amounts of water on inefficient toilets and sinks, and on watering household and municipal lawns. Many groundwater aquifers will still be pumped faster than they are replenished by nature. Millions of acre-feet of treated wastewater will be dumped into the oceans, rather than recycled and reused. Water needed to maintain California ecosystems and aquatic species will come and go with the rains and with human demands. Every drought and flood will have a greater and greater effect on society and the natural environment.[16] And expected water demands will exceed available supplies by several million acre-feet — a gap projected in every official "California Water Plan" produced since 1957. We believe that state water planners have been planning for a future that is increasingly unlikely and undesirable.

During the past 50 years, water-resources planning in California has relied on making projections of 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. 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.

[16] See, for example, previous Pacific Institute reports: "The Societal and Environmental Costs of the Continuing California Drought (Gleick and Nash), July 1991 and "Environment and Drought in California 1987-1992: Impacts and Implications for Aquatic and Riparian Resources" (Nash), July 1993.

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.

The costs to the state of this future – lost industrial competitiveness and revenue, destroyed natural resources, continued uncertainty about long-term water supplies, and further ill-will among urban, agricultural, and environmental interests – can be avoided. Trend is not destiny, and official projections are not inevitable outcomes. It is time to develop new tools and approaches to solving California's water problems.

B. WATER PLANNING FOR THE 21ST CENTURY

Traditional approaches for projecting water demands assumes that the future will look virtually identical to what it does today, with the same social structures and desires and without resource, environmental, or economic constraints. 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.

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.

These initial assumptions can, and should, be directly challenged. The future can look quite different than today, as indeed, today looks quite different than the California of the 1960s. What is needed for the next century is a process that will resolve water conflicts by setting new goals and priorities for water-resource planning. In this report, we present a Vision for California for the year 2020 in which water-resources planning and use are sustainable, both socially and environmentally.

There has been plenty of rhetoric recently around the terms "sustainability" and "sustainable development." What do we mean by sustainability in the context of fresh water resources, and why do we use the term here? 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."* California's water resources should be managed so that today's human and environmental needs are met, and so that the resource base is maintained for the use of future generations. Thus, water-related problems such as the overdrafting of groundwater, the chemical contamination of water supplies, and the loss of aquatic species and unique habitats mean that current water management practices are unsustainable. Continuing these practices is like squandering away an inherited fortune leaving nothing for our children. Sustainable water use requires keeping the resource base intact for future generations rather than destroying it for short-term gain.

Is sustainability a scientific concept? Not exactly. Sustainability is a social goal, much like equity, liberty, or justice. Public value judgments must be made about which needs and wants should be satisfied today and which should be put off or met in a different manner. In Table 4 and here, we present a set of sustainability criteria for water. These criteria, developed over the past year in discussions with academic, governmental, and non-governmental interests working on California, national, and international water problems, embody the value judgments that humans and natural environments should have access to a minimum amount of water necessary for survival, that the renewable characteristics of water resources should not be impaired, and that the process of water planning and management be democratic, fair, and open.

An ethic of sustainability will require a fundamental change in how we think about water. 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.

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 not only a common good and community resource, it is also used as a private good or economic commodity; it is not only a necessity for life, but is 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.

Rather than allowing water policy 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.

We have the opportunity, tools, and ability to create a remarkably different urban and agricultural economy, one that can restore ecosystems and protect the environment while bringing forth innovation, equitable use of resources, meaningful work, and economic security. The vision presented at the beginning of this report offers a positive goal for California water planning and management.

C. THE VISION FOR 2020

A prosperous, healthy California is possible by 2020, with enough water for urban residents, a vibrant agricultural community, and a robust environment. Within 25 years, California can achieve a more sustainable pattern of water use without severe impacts on any particular sector. Groundwater overdraft can be eliminated, urban and agricultural water use can be more efficient and productive, and the protection and restoration of California's natural ecosystems can be enhanced. At the same time, the process of planning and managing the state's water resources can be made more democratic and open, bringing in whole segments of the state's population who have previously been outside the policy making process. The sustainable vision presented here would produce a more stable business environment, reduce the uncertainty over water supplies, and increase the state's economic vitality and competitiveness.

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. 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 applying incremental technological innovations, trying changes in governmental and industrial policies, and by an evolution in personal values. All of these are already common characteristics of California society.

Can these sustainable futures 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. Many economic, political, and cultural forces are at work in society changing our lifestyles, technologies, and institutions, and these forces will continue. The dialogue on how to harness these forces in a new direction must begin now.

D. MAJOR CONCLUSIONS

California water use is not sustainable and current water planning is not up to the task of dealing with the water problems of the 21st century.

- California water policies, both formal and informal, permit or even encourage a wide range of unsustainable practices such as groundwater overdraft, unconstrained urban demand, inefficient water use, and water-supply contamination. Current planning practices continue to use tools developed decades ago when populations and demands were lower, when the principal problem was developing the physical infrastructure to move water around, and when environmental concerns were an unimportant part of the overall equation. All of these conditions have changed, except for our planning institutions.

Continuing down the current path will lead to worsening social, economic, and environmental conflicts over water.

- Present policies and planning will lead to a large gap between water supply and expected demand. Official projections, done by the California Department of Water Resources every few years since 1957, always project water demand exceeding water supply, often by several million acre-feet.
- Present water policies reduce future flexibility and increase the risk of economic instability due to disruptions in water supply. Under conventional projections, the lack of a buffer between demand and supply greatly constrains the flexibility of agricultural, industrial, and commercial water users.
- Present water policies produce uncertainty and a risk of future unreliability during periods of drought and shortage. During dry periods, the only option is emergency response, state-imposed cutoffs, and a higher risk of economic dislocations.

By 2020, California can achieve a more sustainable pattern of water use without severe impacts on any particular sector.

- The focus of this report is to define a new, sustainable approach for water planning and policy, to present a positive water vision for California in the year 2020, and to evaluate how such a vision can be reached. We conclude that such a vision is possible without any single water-using sector bearing the brunt of the changes. We further conclude that over the 25 years between now and 2020, many of the changes we highlight can be accomplished easily.

Modest re-organization of California's agricultural sector can save millions of acre-feet of water.

- The agricultural sector can be more efficient, with lower total water demand and higher agricultural revenues.
- Totally eliminating groundwater overdraft in California is possible with modest changes in cropping patterns. Eliminating groundwater overdraft is a requirement of the sustainability criteria presented above. Current overdraft is about 1.3 million acre-feet per year, and official estimates are that it will still exceed 1 million acre-feet per year in 2020. In our Balanced Groundwater Scenarios, groundwater overdraft can be completely eliminated by fallowing modest amounts of land now devoted to growing water-intensive, low-value crops. If that land is then reallocated to growing other crops already grown in those regions, net agricultural revenue actually increases.
- By 2020, with only modest shifts in cropping patterns, agricultural net water demand could decline by 3.5 million acre-feet while farm income rises by $1.5 billion (1988 dollars). In the Agricultural Restructuring Scenarios, additional shifts in the production of alfalfa, irrigated pasture, rice, and cotton were explored. Changes in acreages planted in these crops back to acreages planted over the previous 25 years (mid-1960s to 1990) produce significant improvements in the overall water productivity of the agricultural sector.

Extensive improvements in the efficiency of residential, industrial, and commercial water use can save millions of acre-feet.

- Average residential water use in 2020 could be 46 percent lower than the current 137 gallons per person per day, using only existing technology. Applying the existing water efficiency standards set in the 1992 National Energy Policy Act, California residential water use will drop substantially. Reducing outdoor residential water use through xeriscaping and changes in watering technology could also significantly reduce residential water use.

- Use of reclaimed water can increase from 0.4 million acre-feet in 1992 to 2 million acre-feet in 2020. The official state goal is to increase the use of reclaimed water to 1 million acre-feet. We estimate that this could easily be doubled, if efforts were made to identify potential uses, and if economic and regulatory barriers to the use of such a resource were reduced.
- Industrial water-use efficiency could increase 20 percent over today's efficiency. The limited industrial water-use surveys done to date for California and elsewhere suggest considerable potential to improve the efficiency of water use. In some sectors, improvements of 50 percent or more are possible. We conservatively estimate an additional 20 percent can be achieved in California industry using existing technologies. Further changes in the make-up of California's industrial sector away from water-intensive industries will further reduce industrial water demand as a function of economic output.

California's environment can be protected far better than it is today by innovative and flexible water management.

- By 2020, more than 2 million acre-feet of water can be reallocated from urban and agricultural uses to a wide range of environmental needs. Savings identified above in the agricultural and urban sectors can be left in streams, rivers, and refuges for California's stressed natural ecosystems. We believe, however, that the absolute amount of water available for California's environment is less important than better management of that water. In particular, flexible management that takes into account seasonal needs and variable quality requirements may prove effective at helping the state restore vital and valuable aquatic ecosystems.
- High mountain streams can be restored to drinkable conditions. It should be possible, at low cost, to restore high-altitude streams in the Sierra Nevada to a drinkable condition. Minor changes in land-use affecting a small number of livestock operators, and better education of the growing number of back-country hikers and campers could have the desired effect.

A major effort is needed to improve our understanding of water supply and use. Major gaps in water data make it difficult to develop and implement rational water plans.

- No one knows for sure how much groundwater is used, who uses it, and for what. This particular lack of data hampers efforts to control groundwater overdraft and impedes the development of rational statewide water planning. While the unconstrained use of groundwater is in the strong interests of some, it is antithetical to rational water planning in a water-short region.
- Residential, commercial, industrial, and municipal data on water use are spotty, at best. There is need for a comprehensive statewide water-use survey. Despite the importance of addressing questions about water demand, far less is known about the characteristics of how California's water is used than about the characteristics of supply.
- Data for on-farm water use are rarely measured directly. Statewide data are needed on how much water is actually applied, evaporated from crops, returned to groundwater, and so on, as a function of crop, irrigation method, climate, and soil type. Improvements in information on agricultural water use will improve the agricultural industry's attempts to become more efficient and profitable.
- The water requirements for restoring and maintaining different ecosystems are poorly understood, complicating rational joint management of water among farmers, cities, and the environment. The needed information includes requirements on flows, timing, and water quality.

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E. MAJOR RECOMMENDATIONS

Pricing policies that subsidize the inefficient use of water at taxpayer expense should be eliminated.

- Most federal and state water subsidies should gradually be reduced and then eliminated. In particular, the 1982 Reclamation Reform Act acreage limitations should be enforced, repayment schedules for federal water projects should more accurately reflect the costs of providing water to different users, and double subsidies should be eliminated.
- Federal crop subsidies for growing low-value, water-intensive crops should gradually be reduced and then eliminated. Of particular concern are crop subsidies for water-intensive crops that receive federally subsidized water as well.
- Urban and agricultural water rates should reflect the cost of service, including non-market costs.

The non-renewable use of groundwater in California should be ended.

- The state should establish a comprehensive groundwater monitoring program and database with open access.
- Institutional mechanisms for managing groundwater use at the local level should be implemented in accordance with standards set by the state. There has been considerable success in limited areas of California to establish local groundwater monitoring and management. The experience in these "adjudicated basins" offer some guidance for setting up such systems statewide. While local management seems both feasible and preferable, some consistent standards set by the state would help prevent abuse of the system.

Efforts to promote the use of water-efficient technologies and practices should be greatly expanded.

- Existing federal and state water efficiency programs should be implemented and expanded. The 1992 National Energy Policy Act put in place residential and commercial water-use efficiency standards for fixtures. Implementing these broadly would have a dramatic impact on urban water demand.
- New and better agricultural, residential, industrial, commercial, and institutional efficiency programs are required. These programs can include regulatory, economic, and educational components. A wide range of sectors are not presently served by any programs that provide incentives, standards, or education on the potential for improving water-use efficiency. Efforts should be made to reach these sectors.
- Water rates for all sectors should be designed to encourage efficient use of water.

Environmental water needs should be better understood and met.

- Critical wetlands should be identified and preserved together with the water needed to maintain them. Degraded wetlands should be restored.
- Water flow and quality standards should be set on a flexible seasonal basis and regularly reviewed.
- Biological resources should be comprehensively monitored.
- Long-term agreements to protect the Bay-Delta region must be implemented. Interim agreements have been reached, but long-term agreements are needed, as are efforts to implement current agreements.
- California's Wild and Scenic rivers must continue to be protected at both state and federal levels. Shortly after the turn of the century, official protections for these rivers will have to be renewed.
- Water should be allocated to protect and restore native anadromous fish runs. Many salmonid species are threatened or endangered because of water policies that failed to take account of fish needs. Integrated management should address these needs.
- Integrated management of agriculture and seasonal wetlands should be pursued further. Some initial success has been achieved with the rice industry. Other options should be explored for joint management with other agricultural sectors.

Legislative, regulatory, and administrative support should be given to those water transfers that improve water efficiency, enhance California's natural environment, and promote the overall well being of rural communities.

- Standards for water transfers should be developed to ensure that they are fair and do not harm the environment. The rapid movement toward permitting water transfers must not ignore possible adverse impacts on ecosystems. At the same time, methods of helping the environment through such transfers should be explored.
- A fund should be established to mitigate adverse impacts of water transfers on rural economies, communities, and the environment. The fund should be supported with fees imposed on transfers. Rural communities may be adversely affected by water transfers over which they have no direct say. These impacts should be evaluated and ways of mitigating adverse economic and social consequences should be developed prior to permitting inter-regional transfers.

Far greater use of reclaimed water is possible in California and should be encouraged through economic and regulatory incentives.

California water-planning institutions should be reorganized to prepare for the 21st century.

- California water planning can be more equitable and democratic by bringing in groups that have been excluded from the process. In particular, rural communities, small farmers, and inner city residents are not typically included in water-planning activities.
- The state should consider separating statewide water planning and data activities from current water project operations. Organizations responsible for building, maintaining, and operating major water projects may not be the proper water-planning organizations of the future since major new projects are increasingly considered inappropriate solutions. Separating these planning and management functions may be appropriate.
- A new independent planning organization can be created by streamlining existing water planning groups. No new bureaucracy is required — rather the existing planning groups from different organizations can be combined into an independent administrative structure.

A statewide system of water data monitoring and exchange should be created.

- Water data must be much more widely collected and distributed. Major gaps in data, and major gaps in the distribution of those data, must be closed.
- An organization that collects, maintains, and freely distributes state water resources data should be created. Far better distribution of water data should be possible, given the rapid growth of electronic data sharing capabilities.

Lifeline water allocations and rates should be implemented for the residential sector.

- A minimum water requirement should be available at lifeline rates for all residents of California.

Land-use planning and water-use planning must be better integrated.

- All new urban developments must demonstrate a secure, permanent supply of water before approval.
- Protection of prime agricultural land and the water required to support these lands should be studied. Efforts to minimize the adverse effects of urbanization on agricultural productivity could be combined with efforts to protect certain water supplies for agricultural communities.

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VIII. Glossary

acre-foot
the volume of water required to cover one acre to the depth of one foot; equals 1,233 cubic meters, 43,560 cubic feet, or 3.259 x 10^5 gallons.

Agricultural Restructuring Scenario (ARS)
the Agricultural Restructuring Scenario (ARS) in this report explores the sensitivity of agricultural water demand and revenue to changes in certain California cropping patterns.

anadromous fish
fish that spend at least part of their life cycle in the ocean and then return to freshwater streams to spawn; includes salmonoid species.

applied water demand
the gross amount of water that is withdrawn from a water distribution system. Agricultural applied water equals the amount of water delivered to the farmgate. Urban applied water is the amount delivered to the intake of a city's water system. Applied water includes the water that returns to groundwater, a stream, canal, or other supply source that can be reused or recycled and thus is not the same as net water demand. (See consumed water, depletion, and net water demand.)

aquifer
an underground bed or layer of earth, gravel, or porous stone that stores water.

average water year
the average annual hydrologic conditions. Because precipitation, runoff, and other hydrologic variables vary from year to year, planners project future scenarios based on hydrologic conditions that typically include average, wet, and drought years.

Balanced Groundwater Scenario (BGS)
this scenario explores changes in cropping patterns such that long-term groundwater withdrawals do not exceed long-term groundwater recharge rates.

Bay-Delta
the Sacramento-San Joaquin river delta extending to the San Francisco Bay. The Bay-Delta is the largest remaining estuarine system on the West Coast of the United States.

consumed water
in this report, consumed water in agriculture is the same as ETAW. (See depletion, ETAW).

CVPIA
Central Valley Project Improvement Act of 1992 (Public Law 102-575).

depletion
the water consumed in a certain area that is no longer available for use by any other party. As defined by the DWR, depletion includes the ETAW, irrecoverable losses, and water that flows to salt sinks (such as the ocean).

dual-distribution piping
a water distribution system that uses one set of pipes for the distribution of potable water and a separate set for distribution of reclaimed water.

Department of Water Resources (DWR)
the California state agency responsible for long-term water planning, operation of the State Water Project, and state water conservation programs.

ecosystem
a system of interacting physical and biological units, including the flora, fauna, and geophysical environment.

evapotranspiration (ET)
the amount of water used by plants for necessary biological functions. Includes the water evaporated from plant surfaces and surrounding area, retained in plant tissues, and transpired (given off).

evapotranspiration of applied water (ETAW)
the portion of the total evapotranspiration that is provided by water applied through irrigation.

fallowed land
farm land that could grow crops but that is left unplanted.

graywater
household wastewater that can be collected for reuse in non-potable uses. Graywater systems exclude all toilet waste.

groundwater basin
a reservoir of groundwater defined by the aquifers underlying a particular land area.

groundwater overdraft
the act of withdrawing more water from a groundwater basin than is recharged over an extended period of time.

hydrologic region, also hydrologic study area (HSA)
a study area used by the DWR to analyze water use and hydrologic conditions. The DWR divides California into 10 hydrologic study areas based on watersheds (see watershed).

irrecoverable losses
the water lost to a salt sink or lost by evaporation or evapotranspiration from a conveyance facility, drainage canal, or in fringe areas.

irrigated crop acreage
the total amount of land area that is irrigated, including acreage that is double cropped.

irrigation efficiency
the ratio of water used for evapotranspiration and the total water applied through irrigation. Efficiency can be calculated at the farm, district, or basin levels.

lifeline rates
subsidized rates for a minimum amount of water.

maf
million acre-feet.

NEPAct
the National Energy Policy Act of 1992 (Public Law 102-486, 102nd Congress).

net water demand
as defined by the DWR, the amount of water needed in a water service area to meet all requirements. It includes the ETAW, irrecoverable losses, and outflow leaving a service area. It does not include the water reused in an area.

normalized demand
as defined by the DWR, normalized demand is the actual demand adjusted to account for water conditions that are not average. Thus, the 1990 water demand used by DWR (1994a) is not what was actually used in 1990, since that was a drought year. Water demand was adjusted upward to reflect DWR's estimates of what water demand would have been had it been an average water year. The DWR's 1990 agricultural water demand figure is based on the average irrigated acreage of the 1980s. The DWR's 1990 urban water demand is based on the average of per capita use from 1980 to 1987.

per-capita water use
the amount of water used by a person. Typically, averaged over some time period and population.

potable water
water suitable for drinking.

subsidence
the lowering of the land surface in response to changes in the characteristics of the underlying earth. Subsidence can occur when the groundwater level is lowered or when underlying materials are removed either by mining or solution or oxidation of solids.

urban water use
includes residential, industrial, commercial, and municipal water use.

wastewater (municipal)
water previously used by residential, commercial, industrial, and institutional users.

water reclamation
the treatment or processing of wastewater to make it reusable.

water recycling
normally involves the capture and reuse of wastewater by one user or use.

water reuse
the use of reclaimed water for direct beneficial purposes.

watershed
the area of land from which all precipitation and/or runoff drains into a single river. Also called drainage basin or river basin.

xeriscaping
the practice of using native vegetation and water-efficient irrigation practices to reduce outdoor water use.

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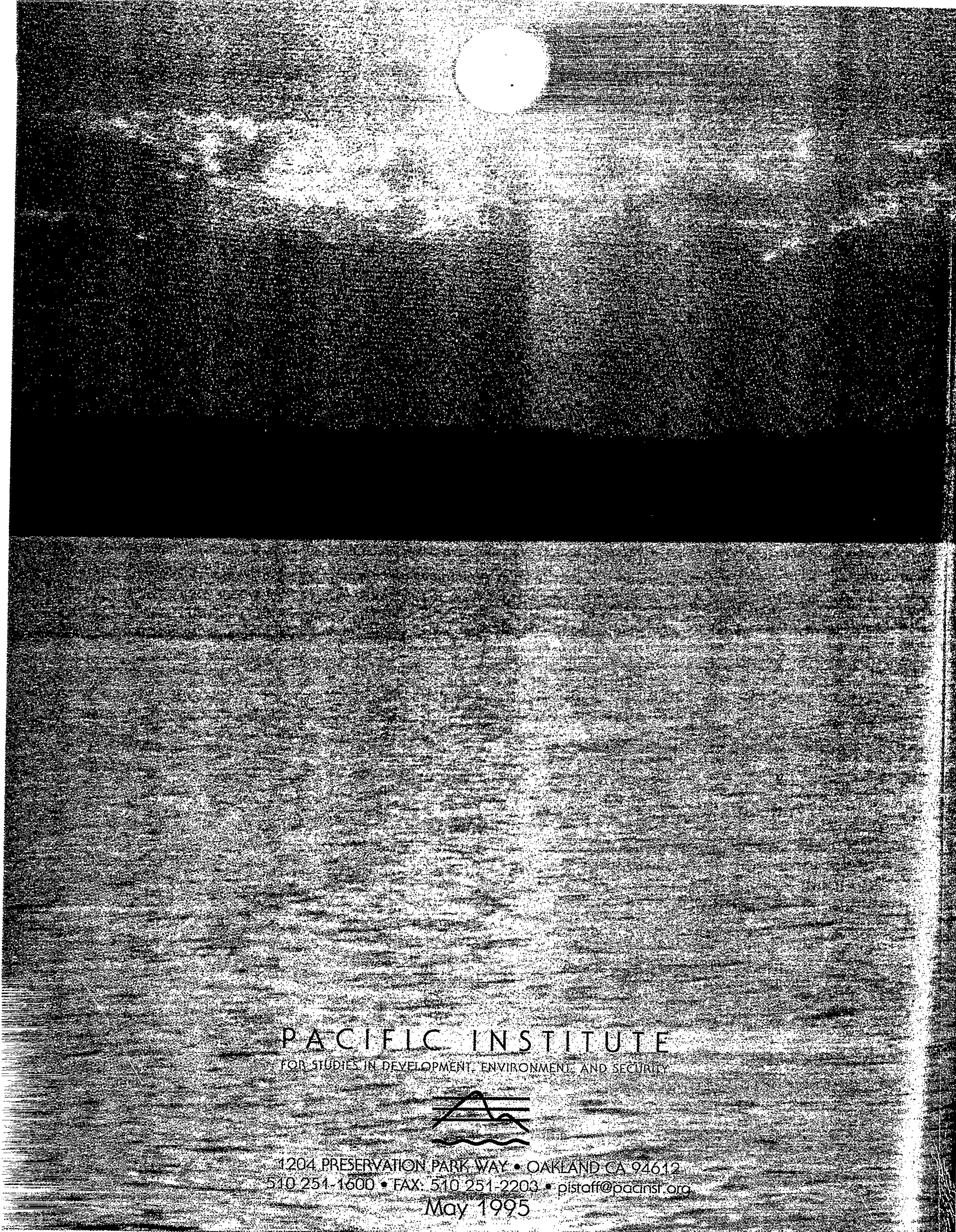

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