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2 California Water Today

We are confronted by insurmountable opportunities.

Walt Kelly, *Pogo*

California's water system is large, complex, and interconnected. Most precipitation falls in the sparsely populated northern and mountainous regions of the state during the winter, whereas most human water demands occur during the late spring, summer, and early fall in the population and farming centers farther south and along the coast. Precipitation also varies greatly across years, making the state susceptible to large floods and prolonged droughts. These conditions have led to the development of vast infrastructure systems that store and convey water to demand centers and that protect residents from flooding. The successive eras of water management over California's history, in turn, have spawned a wide array of management institutions involving local, regional, state, and federal entities.

This chapter reviews major aspects of California's current water system. We start with some basics on water availability: precipitation patterns, movement and storage of water in surface reservoirs and groundwater basins, and water quality characteristics. We then examine water uses, including an assessment of the volumes and values of flows for economic and environmental activities. We also review flood vulnerability and flood management infrastructure. Finally, we look at water management institutions responsible for supply, quality, and flood operations; funding arrangements; and scientific and technical activities that make the system work. At each stage, we highlight strengths and vulnerabilities of the current system and point to changes needed as California enters a new era of water management.

Electrical line over the Los Angeles Aqueduct in the Owens Valley.

Water Availability

California's water supplies are variable and diverse, with most water originating as precipitation. This is then supplemented with imported water, artificial and natural water reuse, and overdraft of groundwater.

Geographic, Seasonal, and Interannual Disparities

On average, roughly 200 million acre-feet (maf) of precipitation fall annually on California. Most of this water evaporates, particularly in the hottest and driest areas of the state. The remainder, known as "unimpaired runoff" (averaging about 75 maf/year) flows downhill into streams and groundwater basins, and becomes available for management and use (Table 2.1).

The geographic disparities in natural water availability are particularly stark: About two-thirds of annual runoff comes from about one-fifth of California's land area, primarily mountainous areas in the northern half of the state (Figure A). In contrast, the driest one-third of the state contributes only about 0.1 percent of total water availability. These driest areas include not only the sparsely

Table 2.1
Regional average annual water availability, storage, and use, 1998–2005 (maf)

			Storage capacity		Water use	
Hydrologic region	Precipitation	Unimpaired water availability	Surface	Ground	Gross	Net
North Coast	53.0	26.0	3.8	11.0	22.0	22.0
San Francisco Bay	6.9	2.3	1.0	3.6	1.9	1.7
Central Coast	13.0	3.7	1.2	45.0	1.5	1.0
South Coast	11.0	2.2	3.1	140.0	5.0	4.2
Sacramento River	57.0	22.0	16.0	91.0	23.0	15.0
San Joaquin River	23.0	8.0	11.0	270.0	11.0	7.3
Tulare Lake	14.0	3.6	2.0	510.0	13.0	8.0
North Lahontan	6.9	2.2	1.2	8.0	0.9	0.5
South Lahontan	11.0	0.8	1.0	210.0	0.7	0.5
Colorado River	5.7	0.2	1.0	170.0	4.6	4.1
California	**200.0**	**71.0**	**41.0**	**1,458.6**	**83.0**	**64.0**

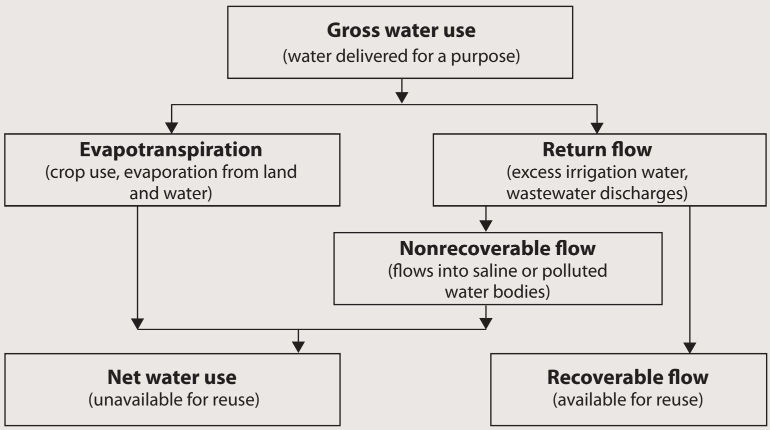
SOURCES: Authors' calculations using regional portfolio data from the California Department of Water Resources (DWR) (2009); data on unimpaired water availability were calculated by J. Viers.

NOTES: The table shows average annual values in millions of acre-feet. See Table 2.2 for more details on water use, Figure 2.1 for a map of hydrologic regions, and Box 2.1 on the distinction between gross and net use. Overall hydrologic region water availability estimates vary across sources and calculation methods. Unimpaired water availability includes surface runoff and groundwater infiltration; total volumes estimated by DWR were distributed across regions by Geographic Information System modeling.

populated deserts of Southern California but also the immense irrigated agricultural areas in the Tulare Basin and the Imperial Valley and rapidly growing urban communities in the Palm Springs area. Most of urban Southern California also has little natural runoff. The large infrastructure projects of the mid-20th century, designed to import water from other regions, have allowed water use patterns to diverge starkly from the distribution of runoff. Net water use (Box 2.1) is twice as high as locally available supplies in the South Coast

2.1

Gross and net water use: some water is reused



Gross (or "applied") water use is the water delivered to a home, business, or farm—not all of which is consumed. Some water—such as excess irrigation water and discharges from wastewater treatment plants—flows to streams, lakes, aquifers, or the sea ("return flow"). Some of this return flow ("recoverable flow") is available for reuse, because it returns to freshwater streams, lakes, or canals or recharges groundwater basins. Net (or "consumptive") water use is that part of gross water that is unavailable for reuse. Net use consists of (1) water consumed by people or plants, embodied in manufactured goods, or evaporated into the air (evapotranspiration) and (2) water return flows discharged into saline or contaminated waters or groundwater basins ("nonrecoverable flow"). Once this water is used, it is generally not available for reuse within the watershed without prohibitive treatment cost.

(continued)

Very little indoor water use is net use, unless the resulting wastewater is discharged to the sea. Most (but not all) landscape and agricultural irrigation becomes net water use, as it evapotranspires to the atmosphere.

Net use can never exceed gross use. But because recoverable flow is often reused, total gross water use usually exceeds total flow into a region. This can be seen by comparing average statewide gross water use (about 83 maf/year) with the total available supplies over the same period (71 maf/year) (Table 2.1).

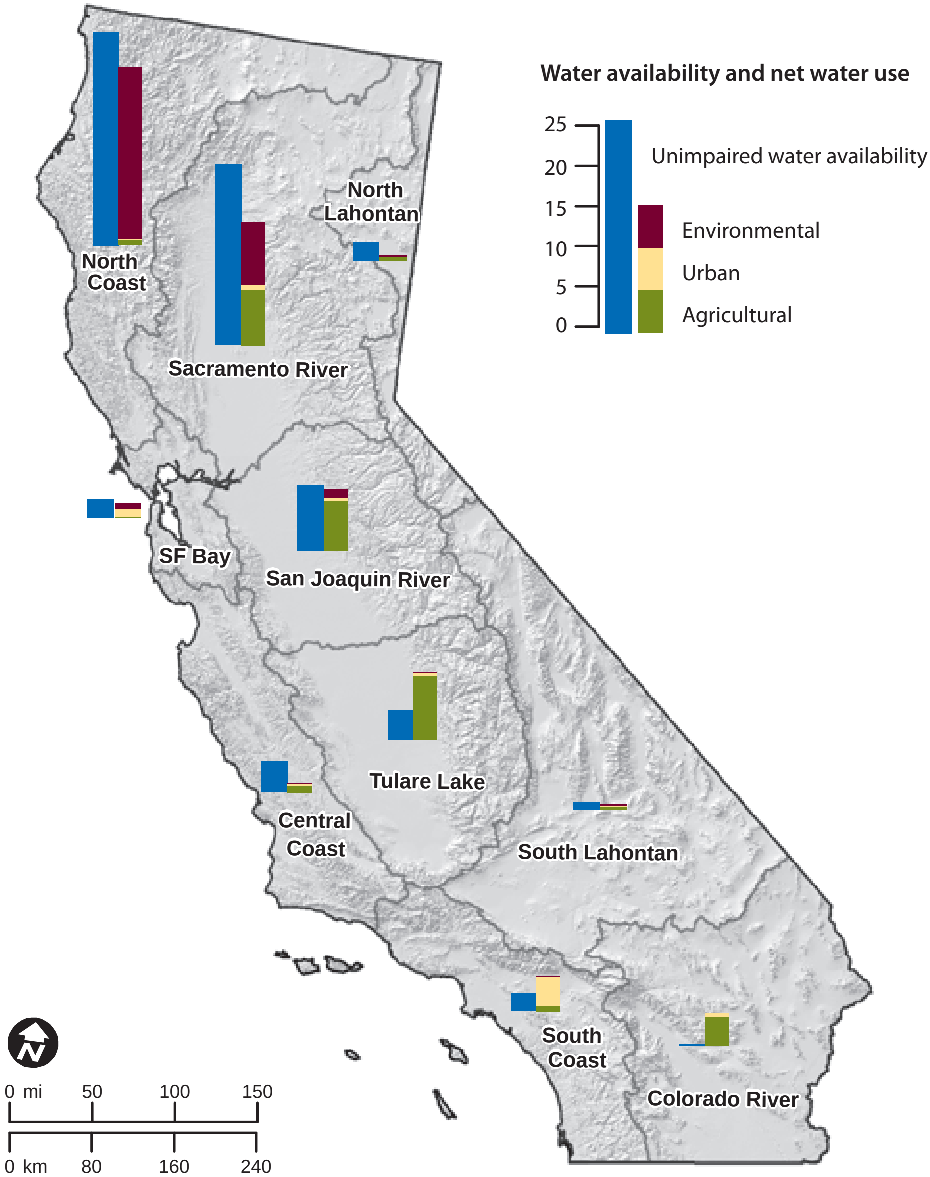
Conservation actions often target reductions in gross water use. But only net water savings provide more water (Ward and Pulido-Velazquez 2008; Clemmens, Allen, and Burt 2008; Huffaker 2008; Hanak et al. 2010; CALFED 2006; Scheierling, Young, and Cardon 2006). In agriculture, achieving significant net water savings generally requires switching to crops that consume less water or reducing irrigated land area. By contrast, irrigation efficiency investments may reduce gross water use per acre but increase net water use on farms by making it easier for farmers to stretch their gross supplies across additional acres of cropland. Reductions in net water use by agriculture usually imply reductions in agricultural production (Perry et al. 2009).

Even when they do not result in lower net use, reductions in water withdrawals from streams and groundwater basins can have environmental benefits, including improved stream flow; reduced pollution runoff into rivers, streams, and beaches (Noble et al. 2003); and reduced energy use and costs for acquiring and treating water (California Energy Commission 2005). For example, a major means of managing soil and aquifer salinization in the southern Central Valley has been to improve irrigation efficiencies, so that less salt-laden water from the Delta is applied to fields. Even though these irrigation improvements make little net water available for use, the resulting runoff is of better quality.

and Tulare Basin, and 20 times as high as local runoff in the arid Colorado River region (Figure 2.1).

Water availability also varies by season and between years. California's Mediterranean climate has wet winters and very dry summers, reflected in the monthly variations in the Sacramento River's natural stream flow (Figure 2.2), the state's largest river. The historical record also shows both very wet years, often with substantial floods, and long multiyear droughts (Figure 2.3). The geologic record of the past 2,000 years shows even larger and longer droughts (Stine 1994).

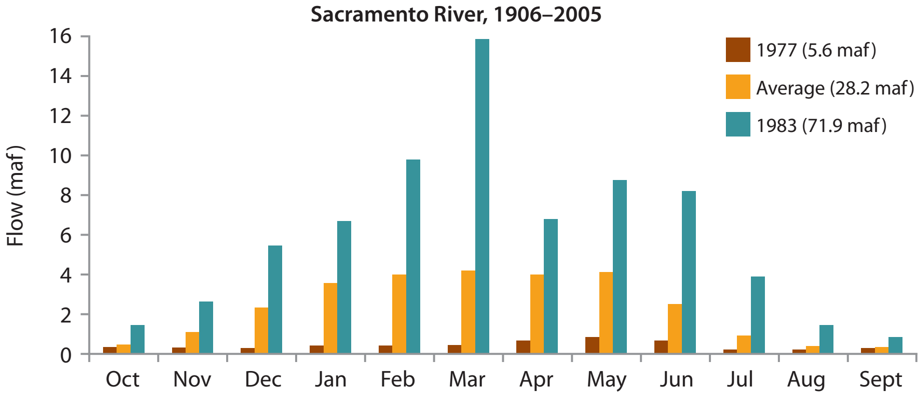
Figure 2.1
Net water use far exceeds local supplies in the southern half of the state



SOURCE: California Department of Water Resources (2009).

NOTES: The map shows annual average values for 1998–2005 in millions of acre-feet. For regional data on water availability and net use, see Tables 2.1 and 2.2.

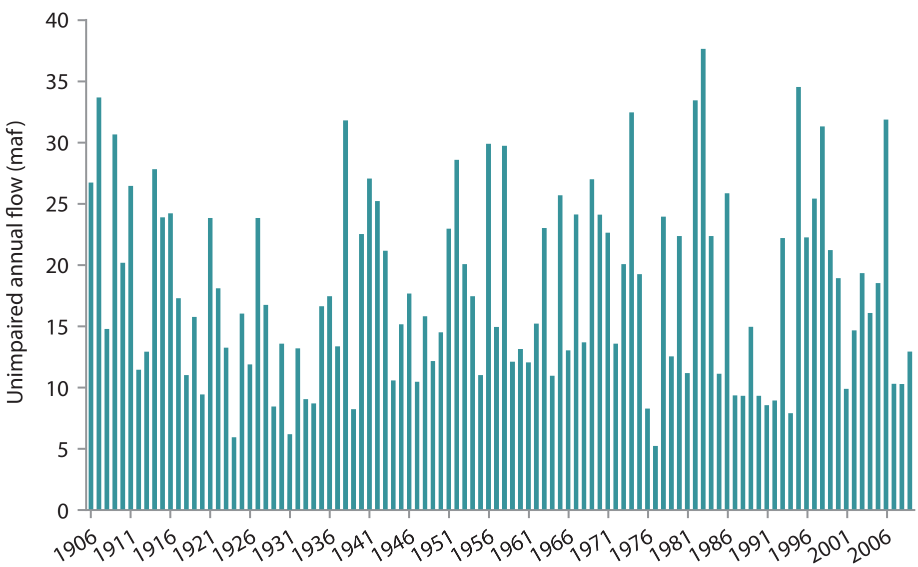
Figure 2.2
Natural stream flow is highest in the winter and spring



SOURCE: California Department of Water Resources.

NOTES: Unimpaired flows (without dams or diversions) on the Sacramento River, 1906–2005. Water year 1977 (October 1976–September 1977) is the driest year on record, and water year 1983 is the wettest year on record.

Figure 2.3
Natural stream flow varies greatly across years



SOURCE: California Department of Water Resources, California Data Exchange Center data.

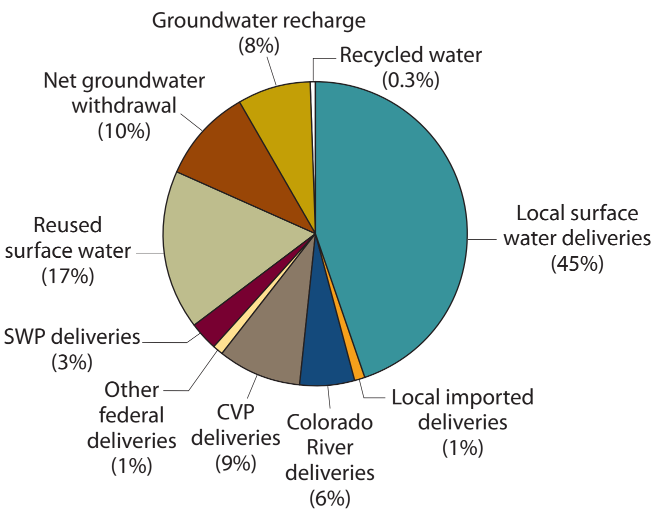
NOTE: The figure shows unimpaired flows (the natural flows that would have occurred without dams or diversions) on the Sacramento River, 1906–2009.

Water Sources: Local, Imported, Mined, and Reused

California supplements water supplies available from in-state precipitation with imports from other states, groundwater mining, and some recovery of wastewater and brackish water following intensive treatment. In addition, available water supplies exceed the amounts flowing into the state because of natural reuse, as excess irrigation water (the amount not consumed by crops) and treated urban wastewater become available for use by others after being returned to streams (Box 2.1).

Figure 2.4 shows the relative importance of these sources in total usable supplies for agricultural, environmental, and urban uses. Overall, more than 80 percent of the initial total (before reuse) is derived from local and out-of-state streams: Three-quarters of these surface flows are from local projects and diversions and roughly one-quarter are from the state and federal projects. About 18 percent of the initial total is supplied by groundwater. Natural reuse constitutes roughly one-quarter of gross supplies (almost half of all groundwater pumping

Figure 2.4
California employs a diverse portfolio of water sources for agricultural, environmental, and urban water uses



SOURCE: California Department of Water Resources (2009).

NOTES: The figure shows sources of gross water supplies, 1998–2005 average. Total water supply is 83 maf per year. Total does not sum to 100 percent because of rounding. SWP = State Water Project. CVP = Central Valley Project.

and one-fifth of surface water).[1] Small, but locally important, amounts of water are derived from other sources, including recycled wastewater and brackish water desalination.

The state's primary imported water source is the Colorado River, which now provides 4.4 maf/year, California's allotment under the federal law that apportions Colorado River water among Arizona, California, and Nevada. These supplies have diminished from a high of 5.1 maf/year in the late 1990s and early 2000s as other states' demands have grown, limiting California's ability to draw on their allotments.[2] Although supplies on the Colorado are also variable (and expected to diminish over time),[3] California's Colorado River entitlement is stable. Other interstate flows are relatively small and affect only local basins in the eastern Sierra Nevada and upper Klamath Basin.

Much of California's runoff flows into the groundwater basins that underlie most of California's land area, where it often becomes a major source of water supply. Over the eight-year period shown in Table 2.1, groundwater pumps withdrew an average of 15 maf/year and accounted for 28 to 42 percent of gross agricultural and urban water use. Groundwater is more important in dry years and is particularly important for agricultural and urban uses in several regions (Figure 2.5). Most of this water is regularly replenished with irrigation water, artificial recharge (from managed recharge basins), seepage from stream flow, and precipitation.

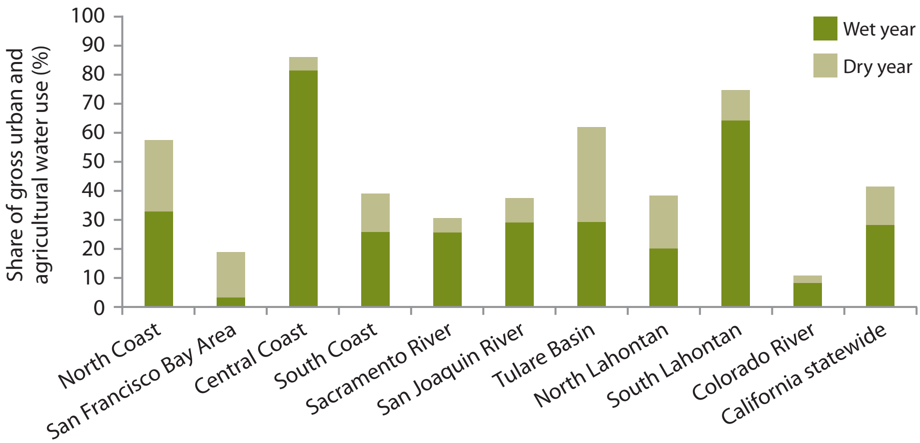
However, in some regions more water is pumped out of basins than is replenished over many years; this is known as overdraft. Chronic overdraft—essentially groundwater mining—could be as high as 2 maf/year on average statewide (California Department of Water Resources 2009). As much as 1.4 maf/year of overdraft occurs from agricultural uses in the Tulare Basin (Kern, Tulare, and Kings Counties) (U.S. Geological Survey 2009). In the Central Coast, the Salinas Basin also suffers from chronic groundwater overdraft (about 19 taf/year [thousand acre-feet per year]), largely from agricultural pumping (Monterey County Water Resources Agency 2001; California Department of Water Resources 1995a). Although groundwater mining can help meet demands during droughts, it is an ultimately unsustainable water source (Harou and Lund 2008).

1. Over the 1998 to 2005 period, surface water reuse ranged from 8 to 15 maf/year and aquifer recharge ranged from 5 to 7 maf/year.

2. As discussed in Chapters 4 and 6, a variety of conservation and water transfer arrangements, known collectively as the Quantification Settlement Agreement of 2003, were developed to help wean California off these surplus water supplies from the Colorado River.

3. On projected declines in Colorado River supplies, see Barnett et al. (2008) and Rajagopalan et al. (2009). Although there is general agreement that supplies are likely to diminish with climate change, there is debate about the likely timing and the extent to which improved water management can forestall extreme shortages of supplies.

Figure 2.5
Groundwater dependence varies widely across California



SOURCE: California Department of Water Resources (2009).

NOTES: The figure shows total groundwater withdrawals as a share of total gross water use in the urban and agricultural sectors in the period 1998–2005. The dry and wet year shares refer to 2001 and 1998, respectively.

Groundwater overdraft and unregulated pumping is a source of growing conflict among water users in many parts of the state, with repercussions including higher costs of pumping, aquifer damage from saltwater intrusion, reduced groundwater availability during droughts, above-ground infrastructure damage from sinking lands, and environmental damage to wildlife in adjacent streams (Chapters 3, 5, 6).

Apart from natural reuse, water reuse also can involve more engineered (and more expensive) treatment and recycling of urban wastewater. The volumes are still quite small: 0.2–0.5 maf/year by the mid-2000s—or about 0.5 percent to 1 percent of California's agricultural and urban use.[4] The amount might rise considerably—to 2 million acre-feet—in the next few decades (Recycled Water Task Force 2003; California Department of Water Resources 2009). To date, recycled water has primarily been used for crop or landscape irrigation, because the stigma of treated wastewater has prevented potable reuse. However, several Southern California agencies are now looking to follow the lead of Orange

4. According to the state's Recycled Water Task Force (2003), over 200 treatment plants produced between 450 to 580 taf/year by 2002. The most recent California Water Plan update estimates that recycled municipal water provided between 0.2 and 0.5 maf/year between 1998 and 2005 (California Department of Water Resources 2009).

County's Groundwater Replenishment System, a partnership between the Orange County Water District and the Orange County Sanitation District, which recharges the groundwater basin with highly treated, potable wastewater (Groundwater Replenishment System, undated). Some parts of inland Southern California have also reclaimed groundwater that was too saline or otherwise contaminated for untreated use (California Department of Water Resources 2009).[5]

Storage and Movement to Population and Farming Centers

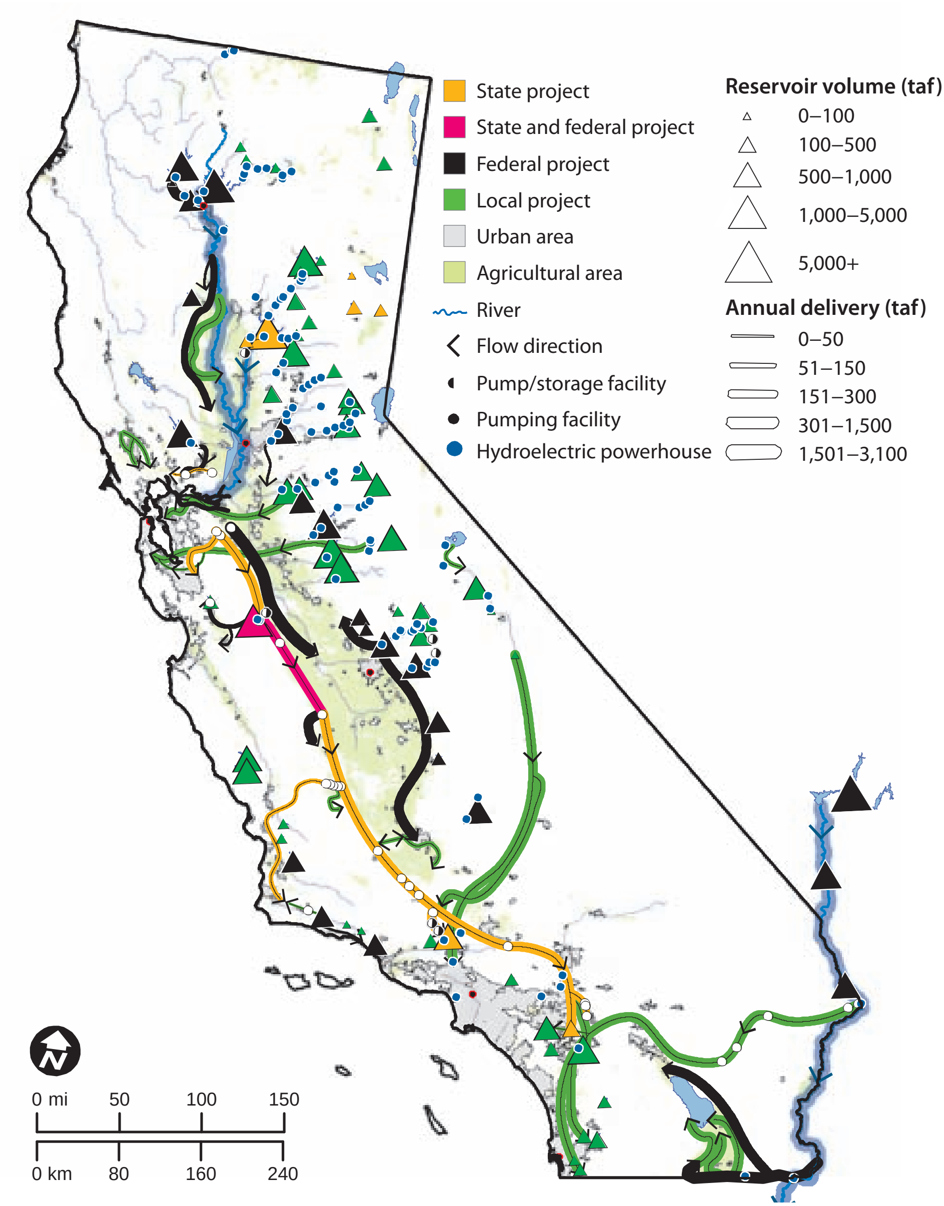
Water is moved from wetter to drier areas through a network of rivers, canals, aqueducts, and pipelines (Figure 2.6). This network of federal, state, and local projects connects local water users with local and statewide water sources and reflects the history of water management (Chapter 1). Although the State Water Project, the Central Valley Project, and other federal projects are the most extensive storage and conveyance projects supporting agricultural and urban water use, major local and regional projects also store and deliver distant supplies to urban centers in the San Francisco Bay Area and Southern California. The hub of both the SWP and CVP systems, and the link between Northern and Southern California, is the network of channels within the Sacramento–San Joaquin Delta. This conveyance hub is at significant risk of failure from flood and earthquake risks to the fragile levees that surround the Delta's man-made islands, most of which now lie well below sea level (Chapter 3) (Lund et al. 2010; Suddeth, Mount, and Lund 2010).

The state's elaborate conveyance network is coupled with an extensive surface water storage system, capable of storing about half the average annual statewide runoff (Figure 2.6, Table 2.1). Most surface storage is located near the source, far from major farming and urban centers. The state's capacity for storing water in aquifers is far greater and much of this capacity is nearer to water users.

Surface and groundwater reservoirs have different advantages and drawbacks. Surface reservoirs can fill quickly and release water fairly quickly, making them flexible for water supply and flood management. But expanding surface storage capacity is costly and ecologically damaging. Groundwater storage

5. As discussed further in Chapter 6, many local agencies are looking to recycled water as a costly, but relatively stable, alternative to supplies imported from distant locations. Ocean water desalination, which relies on similar treatment technologies, also is being considered in some coastal areas. In contrast to coastal areas, where wastewater reuse results in a net expansion of water supplies for the region, expanding reuse of upstream wastewater to support new development is likely to increase upstream net water use and reduce return flows to downstream users (Box 2.1).

Figure 2.6
California has an elaborate network of conveyance and storage infrastructure, controlled by different agencies



capacity is already abundant, but aquifers recharge and empty far more slowly than surface reservoirs, making them more suitable for long-term or dry-year storage. Withdrawal from aquifers typically requires pumping. In California, much recharge is a by-product of crop irrigation, although natural streams and precipitation also contribute. Increasingly, artificial recharge programs are employed. These programs spread surface water over dedicated recharge fields or inject it into wells. Conjunctive use programs, which manage surface water and aquifers jointly, make it possible to expand the system's overall capacity, by storing more water in aquifers during wet years for use in dry years. Although such programs are expanding, the ability to fully exploit the system's potential is limited by the lack of comprehensive aquifer management in many regions, cumbersome institutional rules regarding surface reservoir operations, and limited synthesis of technical information regarding the capacity and condition of groundwater basins (Chapter 6).

As an illustration of this last point, DWR's occasional bulletin on the state's groundwater basins, Bulletin 118, has been issued only twice since 1980. These reports include little analysis or strategic overview of the condition of California's aquifers, how they are employed, or how their management could improve. For instance, although DWR gathers data on over 400 aquifers in the state, these data are not maintained in a way that allows statewide or regional assessments of aquifer conditions, such as overdraft or contamination.

Water Quality Concerns

It is not enough to have "enough" water. Water must also be of adequate quality for each use, either in its natural state or with affordable treatment.

Different qualities for different purposes

Different uses often require different types of water quality. Urban water users require the highest water purity, and costs of treatment increase when the quality of water sources is lower. Drinking water quality standards are being tightened and treatment facilities upgraded as additional contaminants are identified and studied (Calder and Schmitt 2010). This trend is likely to continue and perhaps accelerate, as understanding of public health and water chemistry improves (Chapter 3).

Agricultural water users face significant, but less constraining, water quality concerns, mostly involving excesses of salinity and minerals such as boron that reduce crop productivity and limit crop choices.

The quality of water for environmental uses varies with the species or ecosystem of concern, and water management for human uses has often disturbed the natural conditions in which native species thrive. Artificially high water temperatures in many California streams—resulting from dams, diversions, streamside development, and irrigation—limit spawning and rearing habitat for salmon and other fishes (Chapter 5). Agricultural and urban runoff often adds diverse contaminants to streams, harming aquatic species.[6] In the Sacramento–San Joaquin Delta, native species thrive in murky, muddy water, with more variable salinity, and the system's use as a conveyance hub has made it artificially more stable and clearer, favoring invasive species (Moyle and Bennett 2008; Moyle et al. 2010). A general problem in California is that as streams become more altered in flows and water quality, alien fishes, invertebrates, and plants tend to become predominant (Brown and Moyle 2004; Brown and Bauer 2009). On the other hand, treated wastewater provides much of the flow in some sections of the Santa Ana River, and it is of high enough quality to support a diverse fish fauna, including the endangered Santa Ana sucker (*Catostomus santaanae)* (Brown, Burton, and Belitz 2005).

Salinity and other contaminants

Local runoff and stream flow accumulate dissolved solids, salts, and nutrients as they flow downstream from pristine upper mountain watersheds. Likewise, aquifer quality varies widely. In some areas, groundwater is so pure that it requires no treatment for direct potable use, whereas in others, salinity and other contaminants necessitate blending or costly wellhead treatment.

Statewide, salinity is the most widespread quality concern, both for aquifers and surface flows. Salts come from several sources: They occur naturally in minerals in some soils (where they are released by precipitation or excess irrigation), and they are also present in mineral-based fertilizers and urban wastewater. The salinity of many streams and aquifers has increased as a result of irrigation and urban water uses. When the rate of salt input exceeds the rate of discharge, salts accumulate in soils, water bodies, and aquifers. Salt accumulation can change conditions for ecosystems, reduce the productivity of soils for agriculture, and increase costs for urban water users (Box 2.2).

Salinity problems are greatest in the southern Central Valley and the Salton Sea. High salinity in the lower San Joaquin River from agricultural drainage

6. See Brown (2000) for an illustration relating to the San Joaquin River.

2.2

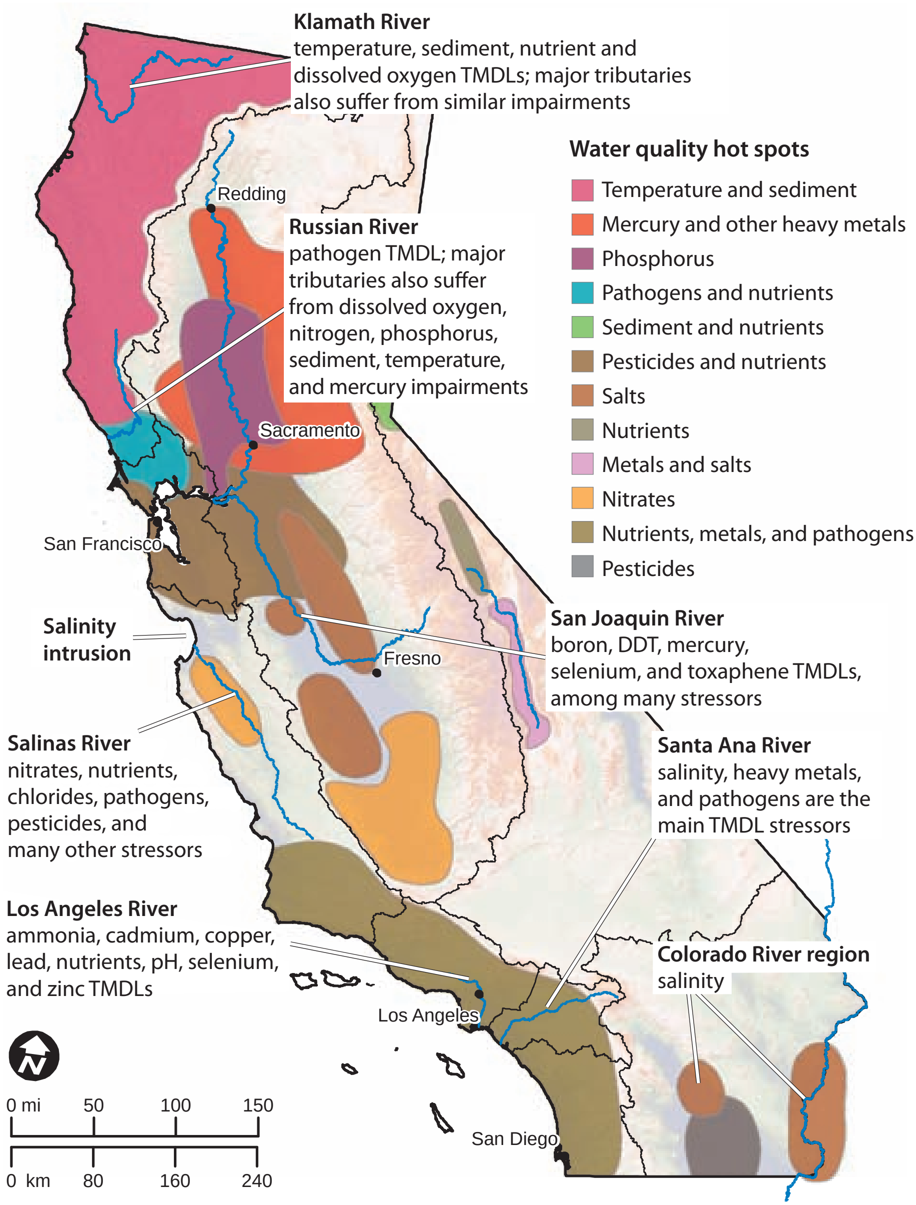
How salty is it?

Sierra runoff contains roughly 50 milligrams per liter (mg/l) of dissolved solids (0.005 percent salt by weight), the Sacramento River roughly 150 mg/l, the Colorado River (at the Nevada border) about 700 mg/l, and the middle reaches of the San Joaquin River about 775 mg/l (0.0775 percent salt by weight). Yields for many crops begin to steeply decline when irrigation water salinity exceeds about 950 mg/l, and urban water treatment and use become much more expensive with salt concentrations above 500 mg/l. Seawater has 33,000 mg/l of salts (3.3 percent salt by weight). Salton Sea and Mono Lake—two "terminal" inland lakes in California that do not flow out to the sea—have salinity levels of roughly 44,000 mg/l and 81,000 mg/l, respectively. (Dead Sea salinity is about 220,000 mg/l (22 percent salt by weight); Utah's Great Salt Lake salinity varies between 50,000 and 270,000 mg/l depending on lake levels.)

has reduced agricultural production, deprived local cities such as Stockton and Lathrop of a water source, and compromised habitat for native fish species. In western areas of the San Joaquin and Tulare Basins, salt accumulations in soils and groundwater have reduced output and removed some land from production, with more land threatened as salts continue to accumulate (Chapter 3). Increasing salinity is diminishing the recreational and environmental uses of the Salton Sea—a man-made inland sea fed by drainage water with no outflow to the ocean and little natural inflow, which is already almost 50 percent more saline than seawater (Box 5.4).

Many other, more localized, water quality problems exist as well (Figure 2.7). The accumulation of excess nutrients including nitrogen and phosphorus often leads to a proliferation of plant life, especially algal blooms, in lakes and sections of streams. Sediment as well as algae growth from nutrients can reduce the clarity of lakes, as with Lake Tahoe. And by-products of fertilizers and pesticides can accumulate in aquifers and streams. In many rural areas, the accumulation of nitrates in groundwater has become a serious concern and a problem for local drinking water users. As a result of groundwater overdraft, some coastal aquifers (e.g., the Salinas and Pajaro Basins in the Central Coast) suffer from seawater intrusion. California must also contend with the legacies of toxic chemicals introduced by mining activities long ago, such as mercury (Chapter 3).

Figure 2.7
California faces numerous water quality problems



SOURCE: Authors' calculations using data from the State Water Resources Control Board.

NOTE: The map highlights only major regional problems, including those for which total maximum daily loads (TMDLs) have been set by water quality regulators.

Pharmaceuticals and a host of other chemicals—often referred to as emerging contaminants—also are causing increasing concern in California (Chapters 3, 6). Establishing a better system for protecting water sources from contamination is a major unresolved water policy challenge for California.

Uses and Value of Water

Water has many uses in California. Households, businesses, industries, and institutions use water in urban areas. Farms use water for crop irrigation and livestock. Water is used to generate power, both directly (hydroelectric generation from falling water) and indirectly (to cool thermal power plants). And, of course, water is essential for healthy aquatic and riparian environments, as well as human recreation.

Estimating water use is problematic in California because of a lack of monitoring and reporting requirements. Table 2.2 summarizes DWR's estimates of the major water supply uses in the agricultural, urban, and environmental sectors for the same eight-year period as Table 2.1.

Table 2.2
Average annual water use by sector, 1998–2005

Hydrologic region	Irrigated Land[a] (1,000s of acres)	Agriculture			Urban			Environmental		
		Gross (maf)	Net (maf)	Net/ gross (%)	Gross (maf)	Net (maf)	Net/ gross (%)	Gross (maf)	Net (maf)	Net/ gross (%)
North Coast	330	0.8	0.6	77	0.2	0.1	74	21.0	21.0	100
San Francisco Bay	81	0.1	0.1	96	1.2	1.0	84	0.6	0.6	100
Central Coast	430	1.0	0.8	74	0.3	0.2	67	0.1	0.1	100
South Coast	250	0.8	0.7	87	4.1	3.5	85	0.2	0.1	50
Sacramento River	2,000	8.3	6.6	79	0.9	0.7	79	14.0	7.6	54
San Joaquin River	1,900	7.0	6.0	85	0.6	0.4	59	3.7	1.0	27
Tulare Lake	3,000	10.0	7.7	74	0.7	0.3	36	1.6	0.1	6
North Lahontan	130	0.5	0.4	80	0.0	0.0	50	0.4	0.2	50
South Lahontan	64	0.4	0.3	81	0.3	0.1	52	0.1	0.1	100
Colorado River	610	3.9	3.7	93	0.7	0.5	70	0.0	0.0	–
California	**8,800**	**33.0**	**27.0**	**82**	**8.7**	**6.6**	**76**	**41.0**	**31.0**	**76**

SOURCE: Authors' calculations using regional portfolio data from California Department of Water Resources (2009).

NOTE: Urban uses include 0.1 maf/year of gross water use (and no net water use) for cooling thermoelectric power generation.

[a] Some land is cropped more than once during the year, so irrigated crop acreage exceeds irrigated land area. Statewide irrigated crop acreage is about 9.2 million acres.

Although DWR has made greater efforts in recent years to quantify and document gross and net water use by sector in different parts of California, these efforts are hampered by a lack of local reporting of water use. Estimating gross use is less difficult where water deliveries are quantified for billing purposes—e.g., surface water deliveries to contractors of the CVP and SWP and metered household water deliveries. But measurement is problematic for self-supplied surface water and groundwater, which have few if any reporting requirements. As a result, DWR must essentially back out estimates of agricultural groundwater use from crop production estimates, themselves imprecise. Net water use is even more approximately estimated.[7] Water use reporting is a highly charged issue, and water users—particularly agricultural users—have successfully resisted legislative efforts to strengthen reporting requirements for groundwater withdrawals and stream diversions. Yet without better reporting, California's water accounting and water rights enforcement will remain approximate at best—an increasingly difficult handicap for policy discussions and water management in a water-scarce state.

How Much Water for the Environment?

Environmental water use and demand estimation is particularly difficult and controversial (Null 2008; Fleenor et al. 2010). Since the late 1990s, the state's Department of Water Resources has published water use estimates that explicitly show dedicated environmental flows as a share of total water use.[8] Environmental water use estimates include flows in designated Wild and Scenic Rivers, required Delta outflows, and managed wetlands. Based on data such as those presented in Table 2.2, it has become common for some observers to argue that the environment receives the lion's share of water supplies (implying that it should not receive more).[9] Indeed, statewide, environmental flows accounted for nearly 50 percent of both gross and net water use in the 1998–2005 period and about 40 percent for agriculture and 10 percent for the urban sector.

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7. For example, net urban use should be significantly higher in the coastal areas because treated wastewater generally flows to the sea. In inland areas, return flows from water users go to rivers and are available for reuse downstream. Oddly, the ratios of net to gross use from DWR water use estimates do not reflect the expected pattern—inland regions such as the Sacramento and Colorado Rivers have higher ratios of net to gross water use than the Central Coast.

8. This practice began with the publication of Bulletin 132-98, the first to consider the environmental share of water as a portion of the total (California Department of Water Resources 1998).

9. As an example, this comment by Tom Birmingham, General Manager of Westlands Water District, in the October 24, 2009, edition of *The Economist*: "Westlands' Mr Birmingham says that, in practice, water usage has already become equal. Whereas agriculture used to consume 80% of the state's water supply, today 46% of captured and stored water goes to environmental purposes, such as rebuilding wetlands. Meanwhile 43% goes to farming and 11% to municipal use."

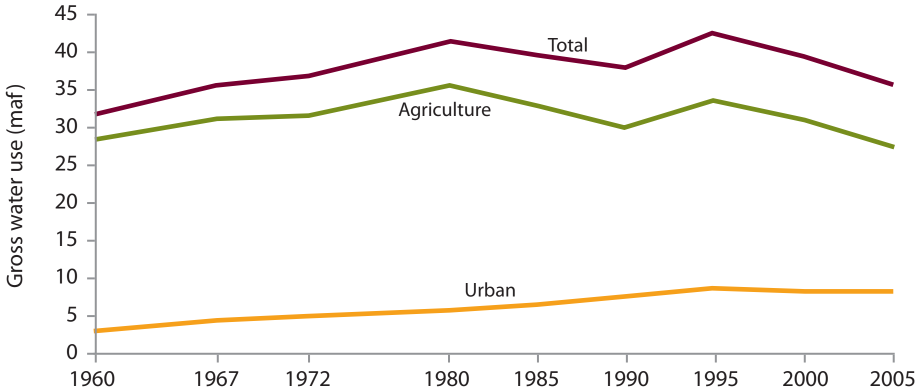
But statewide totals are misleading, because the share of environmental water varies considerably across California. The wet, North Coast region is distinct in two respects: It is largely isolated hydraulically from the rest of California (the major exception being diversions from the Trinity River to the Sacramento River for CVP water supply) and its water is dedicated overwhelmingly to environmental flows. Excluding the North Coast and North Lahontan—another hydraulically isolated region—to look at California's main interconnected water system, average gross water use is 61 maf/year, with about 52 percent agricultural, 14 percent urban, and 33 percent environmental. The environmental share of net use is even lower—23 percent—because much of the environmental water in these regions is available for reuse downstream as Delta exports. In net terms, agriculture accounts for more than three-fifths of the total (62%), urban uses 16 percent, and environmental uses 22 percent.

Looking across hydrologic regions, California has essentially specialized many of its river systems. North Coast rivers are more specialized in environmental flows, whereas many other regions are more specialized for agricultural and urban uses (Figure 2.1). The one other region with a large volume and share of net environmental water use is the Sacramento River Basin, which sends significant net outflows through the Delta and the San Francisco Estuary. In contrast, environmental water use in the Tulare Basin is almost entirely in upstream areas, with almost all of that water subsequently consumed by agriculture downstream. The effectiveness of dedicated environmental flows has been hampered by a range of water and land management practices, including legacies from past land uses, dams, contaminants, and other problems. Chapter 5 examines approaches for improving the effectiveness of environmental water management. Where watersheds and streams can provide more environmental benefits with only limited economic losses (or vice versa), more deliberate specialization may be a key to better performance.

Farms' and Cities' Adaptation to Water Scarcity

California's agricultural and urban water users have been adapting to increasing water scarcity. Over time, the urban sector's share of total human water use has increased with population growth. In 1960, agriculture accounted for 90 percent of gross human water use, but by 2005 this share had fallen to 77 percent (Figure 2.8). Gross urban and agricultural water use appears to have leveled off or declined in recent years, following decades of expansion. (Note that Figure 2.8 shows long-term trends calculated to reflect "normal" water years, so the declines are not the result

Figure 2.8
Total gross agricultural and urban water use has been decreasing



SOURCE: Authors' calculations using data from *California Water Plan Update* (California Department of Water Resources, various years).

NOTES: The figure shows gross water use. Urban includes residential and nonagricultural business uses. Pre-2000 estimates are adjusted to levels that would have been used in a year of normal rainfall. Estimates for 2000 and 2005 are for actual use; both years had near-normal precipitation. Estimates omit conveyance losses, which account for 6 percent to 9 percent of the total.

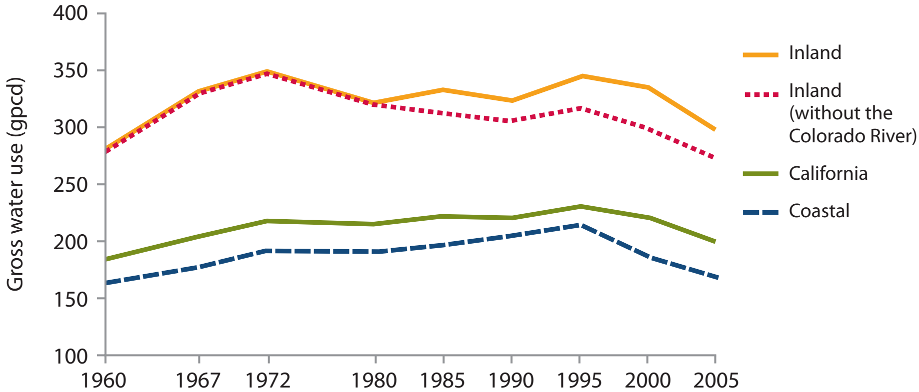
of drought.) Although California's population has continued to grow rapidly, water conservation activities and changes in economic structure (notably, less water-consuming manufacturing) have reduced per capita urban water use enough since the mid-1990s to keep total gross urban water use roughly constant (Figure 2.9).

Gross agricultural water use appears to have been falling since the early 1980s, due to irrigation efficiency improvements and retirement of some farmland with urbanization and accumulating soil salinity.[10] Despite these declines in farm water use, crop production and the value of farm output continue to rise owing to productivity improvements and shifts to higher-value crops. Over the last four decades, yields have risen at an average rate of 1.42 percent per year as both crop varieties and farming practices have improved (Brunke, Howitt, and Sumner 2005). As farmers have shifted to higher-value horticultural and orchard crops, they have adopted more efficient drip and sprinkler irrigation technologies and management practices.[11] Together, rising yields and a shift to

10. Irrigated crop acreage (which counts acreage more than once if it is farmed more than once during the year) fell from a high of nearly 10 million acres in 1980 to roughly 9.2 million acres in the mid-2000s. Irrigated land area (which counts acreage only once) fell from 9.6 to 8.8 million acres (authors' calculations using data from the California Department of Water Resources).

11. Orang, Matyac, and Snyder (2008) report that surface irrigation decreased by about 30 percent from 1972 to 2001 and drip/microsystem increased by about 31 percent, mostly from reduced field crop and increased orchard and vineyard planting. Most of the switch occurred from the early 1990s onward.

Figure 2.9
Gross per capita urban water use is now declining



SOURCE: Authors' calculations using data from *California Water Plan Update* (California Department of Water Resources, various years).

NOTES: Water use is shown in gallons per capita per day (gpcd). Outdoor water use is much higher in inland areas because of hotter temperatures and larger lot sizes (Hanak and Davis 2006). The low-desert Colorado River region, including areas such as Palm Springs, has especially high per capita use from golf-based tourism.

higher-value crops have considerably increased the real dollar value per acre-foot of irrigation water.[12]

Although comparable trends in environmental water allocations are not available, it is likely that new environmental water dedications play some role in the tightening of overall supplies available for agricultural and urban use in recent decades.[13] During this time, California's population and economy have both increased, reflecting a substantial decoupling of economic prosperity from the availability of abundant water supplies. Having more water is no longer as fundamentally important as when California's economy was based largely on irrigated agriculture or mining.

The declining trends in gross agricultural and urban water use may have accelerated in the late 2000s, as a multiyear drought and new restrictions on

12. From 1972 to 1995, the real economic value of output per acre-foot of applied irrigation water increased by 19.3 percent when using the Gross Domestic Product deflator to measure inflation, and by 92.6 percent when deflated using U.S. Department of Agriculture index of prices received by farmers (Brunke, Howitt, and Sumner 2005).

13. For example, since 1993, the federal Central Valley Project Improvement Act has restricted supplies to some agricultural contractors south of the Delta (Chapter 2). Overall pumping through the Delta continued to increase during the late 1990s and early 2000 as State Water Project contractors increased their draw (Figure 2.4), but much of the additional water went to storage for dry years in groundwater banks and Metropolitan Water District of Southern California's new surface reservoir, Diamond Valley Lake. Since the 1990s, Los Angeles has cut its diversions from the Mono Lake and Owens Valley region in response to environmental rulings.

Delta pumping led many urban water agencies to pursue more aggressive conservation measures and as many farmers south of the Delta faced severe water shortages. California water users are likely to face increasing scarcity and the need to continue adapting, as a result of a changing climate and deteriorating conditions of the state's aquatic ecosystems (Chapter 3).

The Economic Value of Water

The debates on how to allocate water across sectors reflect perceptions of the underlying value of water in different activities. Some of these values are easier to measure than others.

Wide disparities in the value of agricultural water use

The economic value of water in agriculture—the largest human use of water—is relatively easy to determine because almost all agricultural production is sold on the market. California has the highest grossing agricultural sector in the nation, but its value is small relative to the state's overall economy. In 2007, the value-added of crop and animal production in the state totaled $22.4 billion, or 1.2 percent of the state's $1.85 trillion gross domestic product.[14] This share nearly doubles (to $40 billion) when food processing is included and would be somewhat higher if the value of farm services and agriculture-related transport were also included. In that same year, agriculture and all related industries accounted for about 5 percent of the state's employment (Figure 1.3). Within some regions, agriculture is far more important as a source of revenue and jobs; it accounts for as much as 15 percent of employment in the San Joaquin Valley.

The value of water use in agriculture varies from a few tens of dollars to thousands of dollars per acre-foot. Table 2.3 shows the estimated water use and revenue generated by major crop types for 2005, along with average revenues per acre-foot of gross and net water used. Irrigated pasture generated less than $50 per acre-foot of net water use—less than 1 percent of the average value of an acre-foot of water used to grow fresh vegetables, flowers, and other horticultural crops. The value of most "field crops" (alfalfa, rice, corn, and various grains and legumes) is also relatively low on average—ranging from $200 to $600/acre-foot

14. Value added, used to calculate gross state product, includes farm revenues from crop and livestock production and forestry and net government transfers *less* the cost of purchased inputs. Data are from the U.S. Bureau of Economic Analysis, gross domestic product by state: www.bea.gov/regional/gsp/. This total is lower than the gross value of farm production (such as that used to calculate crop water values in Table 2.3), which does not subtract the cost of purchased inputs.

Table 2.3
Water use, revenues, and value of water by major crop categories, 2005

Crops	Gross water (%)	Net water (%)	Gross revenues (%)	Irrigated acres (%)	Gross revenues/ gross water ($/af)	Gross revenues/ net water ($/af)
Irrigated pasture	12	11	0.4	9	31	47
Rice	10	9	2	6	127	223
Corn	7	7	1	7	176	258
Alfalfa	18	18	4	12	200	287
Cotton	7	8	3	7	416	551
Other field crops	8	8	3	13	375	573
Fruits and nuts	27	29	44	30	1,401	1,875
Truck farming and horticulture	10	10	42	16	3,724	5,363

SOURCES: Authors' calculations using data provided by DWR staff. Revenue information draws on California Agricultural Statistics and county agricultural commissioner reports.

NOTES: Gross water use = 27.3 maf, net water use = 18.9 maf; crop revenues from irrigated agriculture = $23.9 billion (2005 $); irrigated crop acres (including multiple cropping) = 9.2 million acres. In addition to field corn, corn acreage and water use includes some sweet corn, which is included in the value estimates for truck farming. "Truck farming and horticulture" includes assorted vegetables, some fruits (e.g., melons), flowers, and nursery products. "Fruits and nuts" includes all fruit and nut tree crops plus berries.

of net water used, whereas fruits and nuts (mostly tree crops) average close to $2,000/acre-foot. Within these aggregate categories, the values of some crops are much higher (e.g., high-quality wine grapes sell for much more than table grapes or nuts), and these values also vary with world market conditions (e.g., rice and wheat prices have been higher in recent years because of drought in Australia and Russia, respectively). Also, some of the lowest-value crops (notably pasture and alfalfa) are inputs into the state's meat and dairy production activities, which generate about a quarter of total agricultural revenues. But the general picture is one of striking contrasts, especially if one considers the volumes of water allocated to different commodities; irrigated pasture and all field crops combined accounted for 61 percent of net water use and only 14 percent of gross crop revenues.

Although such simple comparisons do not reflect the complexities of needs for crop rotations and the use of low-value crops for high-value livestock, there still appears to be a considerable volume of low-value agricultural water use in an increasingly parched California. As discussed below, these low-value activities potentially provide the state with some flexibility to cope with droughts and longer-term shifts in demand through the continued development of the water market.

The large differences in crop revenues per acre-foot are reflected in considerable differences in the value of agricultural water use across regions. Coastal areas specializing in fresh vegetables, other horticultural crops, citrus, avocados, and vineyards generate much higher revenues per acre of irrigated cropland than many farms in the agricultural heartland of the Central Valley (Figure 2.10). To some extent, these discrepancies reflect the costs farmers incur to apply water to their fields, a function of seniority of water rights, water subsidies to some CVP contractors,[15] and the financial and energy costs of moving water to users. In coastal Southern California, for instance, farmers pay up to $600 to $800 per acre-foot for State Water Project water that must travel over the Tehachapi Mountains, whereas in Imperial County, parts of the northern Sacramento Valley, and the east side of the San Joaquin Valley, farmers receive water deliveries from local and federal projects for as little as $8 to $40 per acre-foot.[16] Irrigated pasture and low-value field crops are viable only when the water is relatively inexpensive.

Federal crop subsidies artificially boost the value of many low-value crops. Direct subsidies are now provided for roughly half of the state's cotton crop, as well as for corn, rice, and some other field crops.[17] Subsidies to the dairy industry indirectly boost demand for alfalfa.[18] In contrast, prices for the higher-value fruits, nuts, and horticultural crops are entirely driven by local and world markets.

Another way to view the value of water is by examining the costs of shortages. Figure 2.11 shows the incremental revenue loss (or "marginal costs") from reducing irrigation water deliveries by 5 and 25 percent. Much higher losses occur in areas growing higher-value crops, and losses increase substantially with larger cuts. These disparities in agricultural water values provide incentives for farm-to-farm water sales. Many farmers with more senior and secure water rights grow relatively low-value crops, whereas some junior rights holders, such

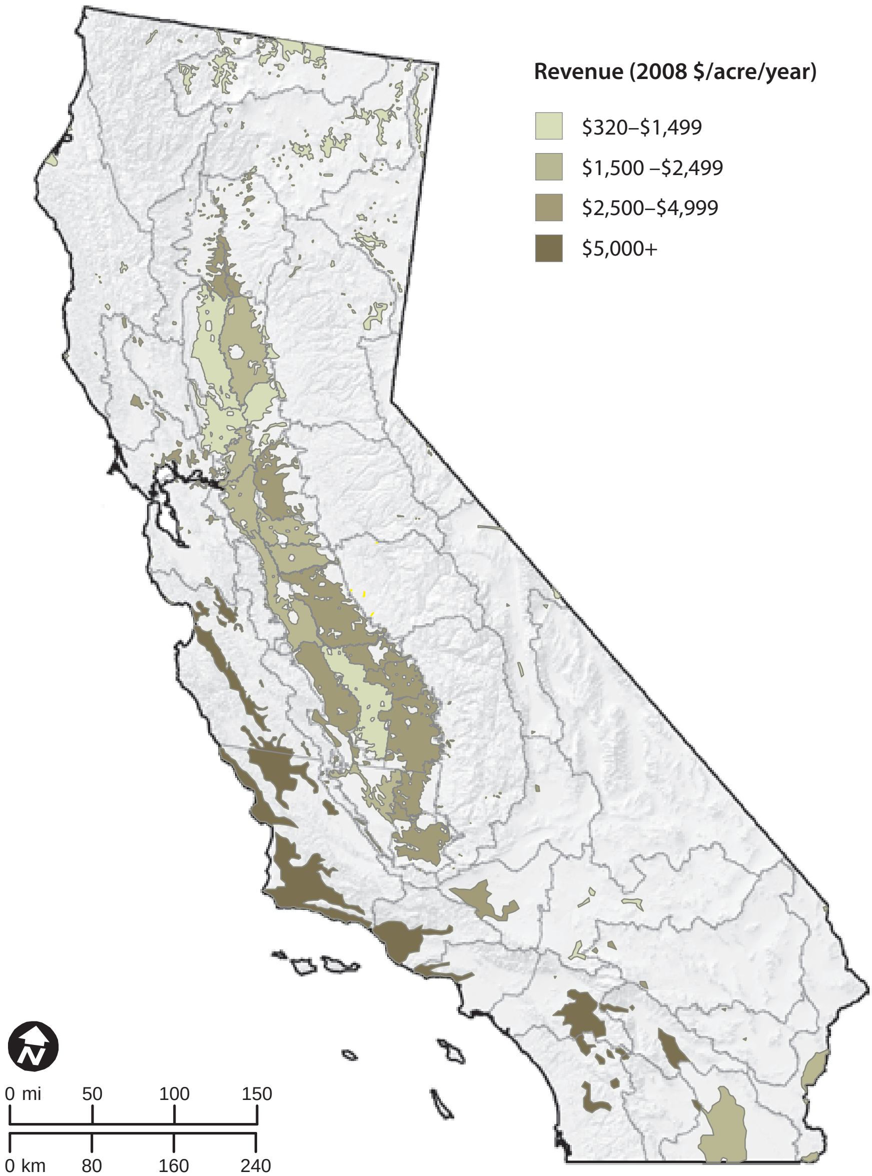
15. The estimated yearly subsidy to farmers receiving CVP water, relative to the full-cost rate, is roughly $60 million (Environmental Working Group 2004). In addition to its subsidized contractors, the CVP also delivers about 2.6 maf of water to "settlement" and "exchange" contractors who were already receiving the water before the CVP began operations at low (but not subsidized) prices (Hanak et al. 2010).

16. Comprehensive information on agricultural water prices is not available, but most large irrigation districts publish their rate structures.

17. In 2005, for instance, direct subsidies to cotton, rice, corn, wheat, and barley amounted to $534 million (current dollars), roughly 16 percent of the gross revenue of all field crops (Environmental Working Group undated).

18. Dairy subsidies vary considerably by year. In 2009, they were as much as $125 million in California (Environmental Working Group undated).

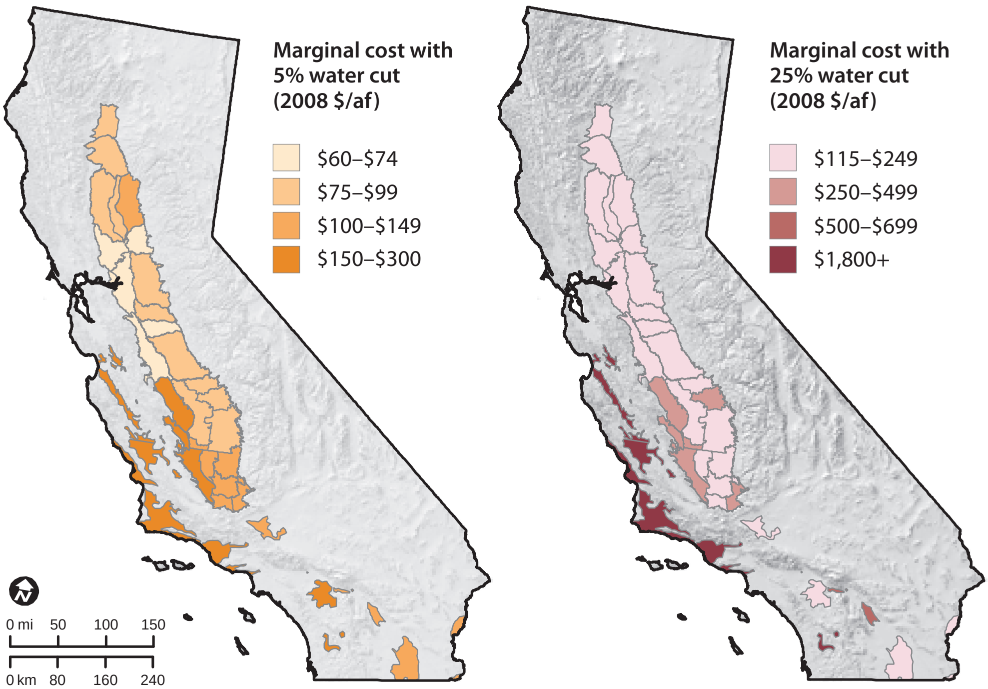
Figure 2.10
Agricultural revenues per acre vary widely



SOURCES: County Agricultural Commissioner Reports and Statewide Agricultural Production model.

NOTE: Values are calculated for DWR planning areas; the borders of these areas are shown on the map.

Figure 2.11
Costs escalate quickly with higher agricultural water cutbacks



SOURCE: Statewide Agricultural Production model.

NOTES: The maps show the loss of farm revenue incurred by the last acre-foot of water lost when supplies are reduced by 5 and 25 percent. This is the value that farmers would be willing to pay to purchase an additional acre-foot of water to apply to their fields.

as those in the west side of the San Joaquin Valley, have more productive farms but less secure water supply contracts. Water transfers are particularly valuable when farmers with less secure rights grow tree crops, which will die without water.

Water subsidies are not necessarily a hindrance to water marketing, because farmers still have incentives to sell water as long as they can earn more by selling water than by producing crops. In contrast, crop subsidies can create a disincentive if the subsidy payment is tied to the volume of production. Crop subsidies are now less closely tied to crop acreage and production than in the past, with payments based on past volumes and acreage. However, it is likely that farmers still consider the potential for the loss of subsidies with program adjustments when they make their planting decisions (Bhaskar and Beghin

2009; Blandford and Josling 2007).[19] Changes in federal farm policy are needed to break this link and facilitate more efficient use of water.

When water to some CVP contractors became less reliable as a result of the listing of several species for protection under the Endangered Species Act and the environmental water allocations mandated by the Central Valley Project Improvement Act of 1992, farm-to-farm water transfers became an important tool for supplementing farm water supplies on the western side of the San Joaquin Valley, including the Westlands Water District (Hanak 2003). The still large discrepancies in crop values and water use suggest the potential for much more use of water markets in response to further regulatory cutbacks and drought-related scarcity. For instance, during the recent drought, irrigated pasture still accounted for a sizable share of gross water use within the San Joaquin Valley.[20] In Chapter 6, we discuss obstacles to continued development of water markets, including institutional and legal barriers, infrastructure limits (e.g., the difficulty of moving water from the east to the west side of the San Joaquin Valley), and concerns within source regions about local economic harm from transfers. Getting past these obstacles is an important priority for California water policy.

Little growth in urban water use despite economic growth

Urban water use is less directly linked to economic prosperity than in the case of agriculture, suggesting considerable flexibility to reduce use, if done carefully, without reducing regional or statewide economic activity. As a rough illustration, the state's economy was 2.4 times larger in real terms in 2005 than in 1980, despite a 14 percent drop in total gross water use and a 30 percent increase in urban gross use (Figure 2.8). The economy grew another 14 percent from 2000 to 2005 with no increase in gross urban water use and an 11 percent decline in gross agricultural water use.[21]

Urban water use has a large, but less direct, effect on economic prosperity (Figure 2.12). Industrial water use tends to have an extremely high marginal

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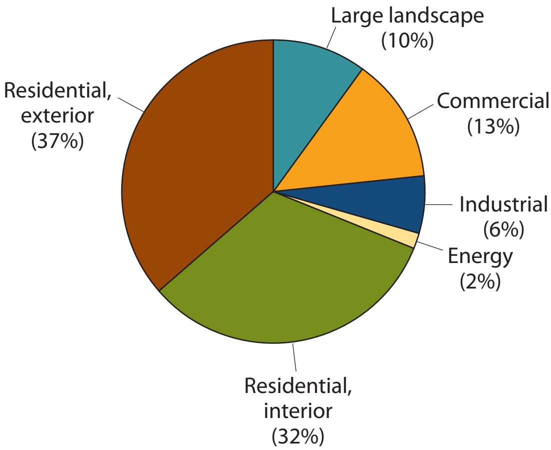
19. As an example, cotton subsidies are tied to past cotton acreage, but farmers are not allowed to grow fruits and nuts on that acreage and continue to qualify for the subsidy.

20. According to DWR statistics, in 2005, irrigated pasture accounted for 12 percent of gross water use in the San Joaquin River hydrologic region. In 2008, County Agricultural Commissioner Reports estimate that acreage of irrigated pasture within the eight-county San Joaquin Valley had fallen by 20 percent, suggesting some adaptation but considerable remaining water use for this low-value crop.

21. Within agriculture, the real value of farm output was 1.12 times higher in 2005 than in 1980, despite a 23 percent decline in applied water on farms and a 7 percent decline in irrigated crop acreage (authors' calculations using gross state product data from the U.S. Bureau of Economic Analysis and water use data from the California Department of Water Resources).

Figure 2.12
Landscaping accounts for at least half of gross urban water use



SOURCE: California Department of Water Resources (2009).

NOTES: The total (8.3 million acre-feet) excludes conveyance losses and active groundwater recharge. Water for landscaping uses include residential exterior, large landscapes (e.g., parks, golf courses, cemeteries), and a portion of commercial and industrial water use.

value, because of high potential for revenue and job losses with cutbacks, but it accounts for only about 6 percent of total urban use. Preventing shutdowns of chip manufacturing and other water-intensive industries was an important impetus of the emergency drought water bank that the state established during the prolonged drought of the late 1980s and early 1990s (California Urban Water Agencies 1991).

The value of water and the costs of cutbacks, while substantial, is harder to measure in most other urban uses. Water is important for businesses involved with large landscape water uses, e.g., golf courses, as well as for businesses relying on household water use, such as landscaping firms and swimming pool vendors. These businesses often can use less water without losing revenues, although this often requires some changes in the business (e.g., switching from lawn maintenance to installing low-water-using gardens). Water shortages primarily generate costs to end users, in terms of either new equipment (e.g., more water-efficient plumbing, which provides similar service while using less water), or inconvenience (e.g., taking shorter showers, letting lawns go brown, or leaving pools empty). Economists measure these noncommercial values of urban water in terms of how much people would be willing to pay not to have their supplies reduced.[22] This willingness to pay increases as water becomes scarcer, and it is likely higher in the short term than in the longer term—when time allows adaptation with new technology, such as more efficient shower heads or low-water-using plants.[23]

As shown in Chapter 6, continued urban conservation will be important for managing scarce water resources, and this shift will be most effective if technologies, tastes, and habits can adapt to minimize the costs of adjustment. An especially important frontier will be outdoor water use, which now accounts for most net urban use (residential exterior, large landscape, plus some proportion of commercial and industrial uses—Figure 2.12). Shifting landscapes from thirsty lawns to low-water-using plants can greatly reduce net urban water use (Hanak and Davis 2006).

Do urban water users pay too little?

In water management circles, it is often said that California's urban water users pay too little for water. A comparison is made with monthly cell phone bills, and the implication is that consumers are getting a bargain on their water bill relative to the value of the water to them—or the amount they would (or should) be willing to pay. The comparison with cell phone bills is apt. As of 2006, the average price of treated water delivered to households was roughly $960 per acre-foot (in 2008 $), and the average monthly water bill for single-family households was $42, less than a typical cell phone subscription (Table 2.4).

The important question, however, is not whether users pay too little relative to the value of water to them—this is true, on average, for most goods and services.[24] Rather, what matters from a water policy perspective is whether they pay enough to cover the full costs of providing water, including the capital and maintenance costs to the water utility and the costs of protecting environmental values affected by water diversions. As discussed below in our review of water system finances, the first part of this answer is a qualified "yes," but the second part is a definite "no." Not only can adapting water prices to reflect the full cost of water generate an appropriate stream of funding for public benefits of the water system, it can also send the right signal to consumers to use the resource more efficiently (Chapter 6).

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22. See Renwick and Green (2000), Barakat & Chamberlin, Inc. (1994), Genius et al. (2008), Jenkins, Lund, and Howitt (2003), Rosenberg, Howitt, and Lund (2008), Rosenberg et al. (2008), and California Department of Water Resources (2009).

23. Economists also measure the consumer benefits from using water under different water price structures by comparing the additional benefits from additional amounts of water consumed to the marginal cost (price) of that amount (Hewitt and Hanemann 1995; Olmsted, Hanemann, and Stavins 2007; Hall 1996). As discussed in Chapter 6, the social goal is to design an economically efficient, revenue sufficient, and politically acceptable water rate (Hall 2000, 2009).

24. Economists refer to the excess in willingness to pay over price as the "consumer surplus."

Table 2.4
Household water and wastewater costs in the mid-2000s (2008 $)

Region	Average yearly gross water use (af)	Average water price ($/af)	Average monthly water bill ($)	Average monthly wastewater bill ($)	Water and wastewater bills as a share of median income (%)
San Francisco Bay Area	0.37	1,190	36	31	1.07
Central Coast	0.38	1,857	59	28	1.68
South Coast	0.58	985	48	23	1.46
Inland Empire	0.59	748	36	18	1.28
Sacramento Metro Area	0.49	789	32	26	1.23
San Joaquin Valley	0.63	545	29	19	1.26
Rest of state	0.47	886	35	25	1.78
California	**0.52**	**959**	**42**	**24**	**1.36**

SOURCES: Authors' calculations using data from Black and Veatch (2004, 2006) for water and wastewater rates and the U.S. Census for household incomes.

NOTES: The table reports charges for single-family households. Water rates are for 2006; wastewater rates are for 2004; both are converted to 2008 dollars using the consumer price index. The sample includes 443 water service areas and 560 wastewater service areas. The considerable regional variation in water prices reflects differences in local infrastructure and water supply costs. The regional breakdowns here are based on counties and differ slightly from the hydrologic regions in Tables 2.1 and 2.2. Communities in the Inland Empire (Riverside and San Bernardino) are located in the South Coast, the South Lahontan, and the Colorado River regions. San Joaquin Valley includes the San Joaquin River and Tulare Basin regions. "Rest of state" includes rural counties in the Sacramento River region, the North Coast, and the North Lahontan regions.

Environmental water: an undervalued resource

Environmental flows, healthy watersheds, and the services they provide—often known as *ecosystem services*—add economic value to California (Box 2.3). However, these benefits are often not readily apparent because the market does not generally put a price on them (National Research Council 2005; Brauman et al. 2007; Daily et al. 2009). As a result, the value of ecosystem benefits is overlooked in many cost-benefit analyses used to evaluate water investments. The failure to consider environmental values has contributed significantly to the degradation of aquatic ecosystems (Introduction, Chapter 5).

Although new tools are emerging to estimate the economic values of ecosystem services, such valuation is not without challenges (Boyd and Banzhaf 2006). The difficulties stem, in part, from the different methods of valuation that must be used to compare services (Freeman 2003). Some commodities produced by freshwater ecosystems, such as produce and fish, have easily identified market values. For instance, in 2007, fisheries and

2.3

Freshwater ecosystem services in California

Ecosystems provide many economic services. A major global study done for the United Nations considered four overlapping categories: provisioning, regulating, cultural, and supporting services (Millennium Ecosystem Assessment 2005). Some services are easier to measure than others.

Provisioning services. Provisioning involves the production of (1) food, both from irrigated agriculture and fisheries; (2) materials, including timber and cotton; (3) fresh water, for household, industrial, and service uses; and (4) hydropower. Provisioning services have the longest tradition of economic valuation and are regularly calculated for water management projects.

Regulating services. Freshwater ecosystems also regulate a range of environmental conditions that affect human well-being. Some prominent examples in California include (1) flow regulation, including use of watersheds and floodplains to recharge groundwater basins and reduce downstream harm from floods; (2) water quality regulation, including the use of wetlands and rivers to remove nutrients and pesticides from waterways; and (3) climate regulation, including regional air quality (e.g., reducing airborne particulates and summer temperatures) and carbon sequestration in floodplain wetlands and riparian forests. Economic benefits from these services are rarely measured.

Cultural services. Some cultural services have direct, measurable market value: recreation, ecotourism, and the aesthetic values of scenic views and parks. Cultural services with nonmonetized value are more difficult to measure: spiritual renewal, religious and cultural values, and the use of freshwater ecosystems for formal and informal education.

Supporting services. Many of California's freshwater ecosystems provide support for other economic activities that are only realized over very long periods of time or through indirect connections to other ecosystem services. Supporting services include soil formation and fertility, particularly in floodplain and wetland settings subject to seasonal flooding; removal of carbon dioxide through photosynthesis; nutrient cycling (the natural cycling of nutrients necessary to sustain life in freshwater ecosystems); and water cycling (regulating the rates of movement and pathways of water through the hydrologic cycle). Supporting services are rarely measured.

forestry accounted for $7.6 billion of gross state product (2008 $).[25] Other services are essentially public, free for use, such as recreation, and must be valued using nonmarket methods, which can generate wide ranges of estimates. Some services, particularly support services, have no easy method for measurement.

25. Bureau of Economic Analysis gross state product data (current values, converted to 2008 values using the ratio of nominal to real U.S. gross domestic product).

For this reason, many ecosystem service valuation efforts focus on a few services that can be most easily quantified and tend to ignore or qualitatively discuss the rest.[26]

These difficulties notwithstanding, California has much to gain by adopting a more comprehensive approach to assessing the value of ecosystem services. Even where full economic valuation is not practical, an approach that considers nonmarket functions of aquatic ecosystems can inform and guide decisions for water supply and flood management to maximize overall benefits (Chapters 5, 6). Considering the value of ecosystem services comports well with recent state legislation and policies seeking to establish "co-equal" goals for ecosystem health and water supply (Chapter 1). This approach also can help to dispel the myth that healthy aquatic ecosystems conflict with a healthy economy (Hanak et al. 2010).

Water and Energy

Water is heavy; average urban use (about 200 gallons per capita per day) comes to over 1,500 pounds a day. So the energy needed to move water can be considerable. This is particularly true for Southern California's urban water supplies, which often involve lifting large amounts of water over mountains. These pumping costs alone offer considerable incentive for water conservation (Wilkinson 2000). In addition to long-standing management concerns about the high cost of energy involved in water production and use (Palmer and Lund 1986), there have been growing policy concerns about greenhouse gas emissions from both the production and use of water. In the latter context, it is frequently reported that water use accounts for roughly 20 percent of the state's electricity use, making it a target for state policy efforts to reduce emissions (California Air Resources Board 2008). However, public discussions of this issue do not usually recognize that almost three-quarters of water-related energy use occurs in the homes, businesses, offices, and farms of end users (Table 2.5). Less than one-quarter is devoted to operating local, regional, and statewide water infrastructure.

Most water-related energy use is in the urban sector. The most energy-intensive urban uses involve water heating, electricity for washing machines, chilling water and ice, and in-building pumps for spas, hot water circulation, evaporative coolers, etc., as well as industrial and commercial processes. Agricultural end

26. A recent study by the Science Advisory Board for the U.S. Environmental Protection Agency (2009) discusses a variety of methods for valuing ecosystem services: (1) measures of public attitudes—surveys and focus groups that elicit public preferences for ecosystem services, (2) economic methods—methods to estimate how much people are willing to spend to avoid losing a service, and (3) civil valuation methods—public referenda or initiatives, which provide information about how much the voting population values particular services.

Table 2.5
Water-related energy use in California, 2001

	Electricity		Natural gas	
	Gigawatt hours	Share of state total (%)	Million therms	Share of state total (%)
End uses		14.1		31.2
Urban	27,887	11.1	4,220	31.1
Residential	13,526	5.4	2,055	15.1
Commercial	8,341	3.3	250	1.8
Industrial	6,017	2.4	1,914	14.1
Agricultural	7,372	2.9	18	0.1
Water supply and treatment		4.3		0.1
Urban	7,554	3.0	19	0.1
Agricultural	3,188	1.3	0	0
Wastewater treatment	2,012	0.8	27	0.2
Total water-related energy use	48,012	19.2	4,284	31.6
Total California energy use	250,494	100.0	13,571	100.0

SOURCE: California Energy Commission (2005).

NOTE: Statistics on natural gas use refer to the portion of natural gas that is not used as an input in electricity production.

uses mainly include operating pumps for groundwater and irrigation systems. Infrastructure-related energy ("supply and treatment" in Table 2.5) is primarily for pumping supplies through conveyance channels and (in the urban sector) to move water in and out of treatment plants and distribution networks. The high energy content of some end uses means that energy costs drive the economics of some water conservation activities (especially for hot water). As with some energy efficiency measures, water use efficiency investments that reduce hot water use can save customers money within a short time.[27] Energy costs also affect the economics of design and operating decisions by water utilities. The high energy requirements of seawater desalination makes this technology particularly vulnerable to rising energy prices (Semiat 2008).

Water also is a major source of energy. California relies on hydropower for between 15 and 30 percent of its annual electricity generation, depending on annual runoff and droughts (Madani and Lund 2010).[28] The flexibility of hydro-

27. On water, see Gleick et al. (2003). On energy, see McKinsey & Company (2007).

28. Statewide hydropower revenues exceed \$2 billion per year (authors' calculations, assuming 34,000 gigawatt hours × \$0.05 per kilowatt hour = \$1.7 billion per year at average wholesale prices, plus the ancillary services of hydropower, such as maintaining reserve capacity and regulating voltage on the grid).

power makes it particularly valuable for meeting peak summertime demands. This resource will diminish if California's climate becomes drier, as less stream flow means less fuel for hydroelectric power plants.[29] Hydropower management also has major implications for ecosystem health, because of the disruptions caused by dams and flow alterations to the aquatic environment (Chapter 5).

Flood Vulnerability and Flood Management Infrastructure

Protecting people and businesses from flooding has been a long-standing concern of California water management (Chapter 1). The current system of flood management infrastructure includes surface reservoirs (many of which also provide water supply storage), levees, and flood bypasses (Figure 2.13). This infrastructure is used in conjunction with land use regulations, insurance, and warning systems (Chapter 6).

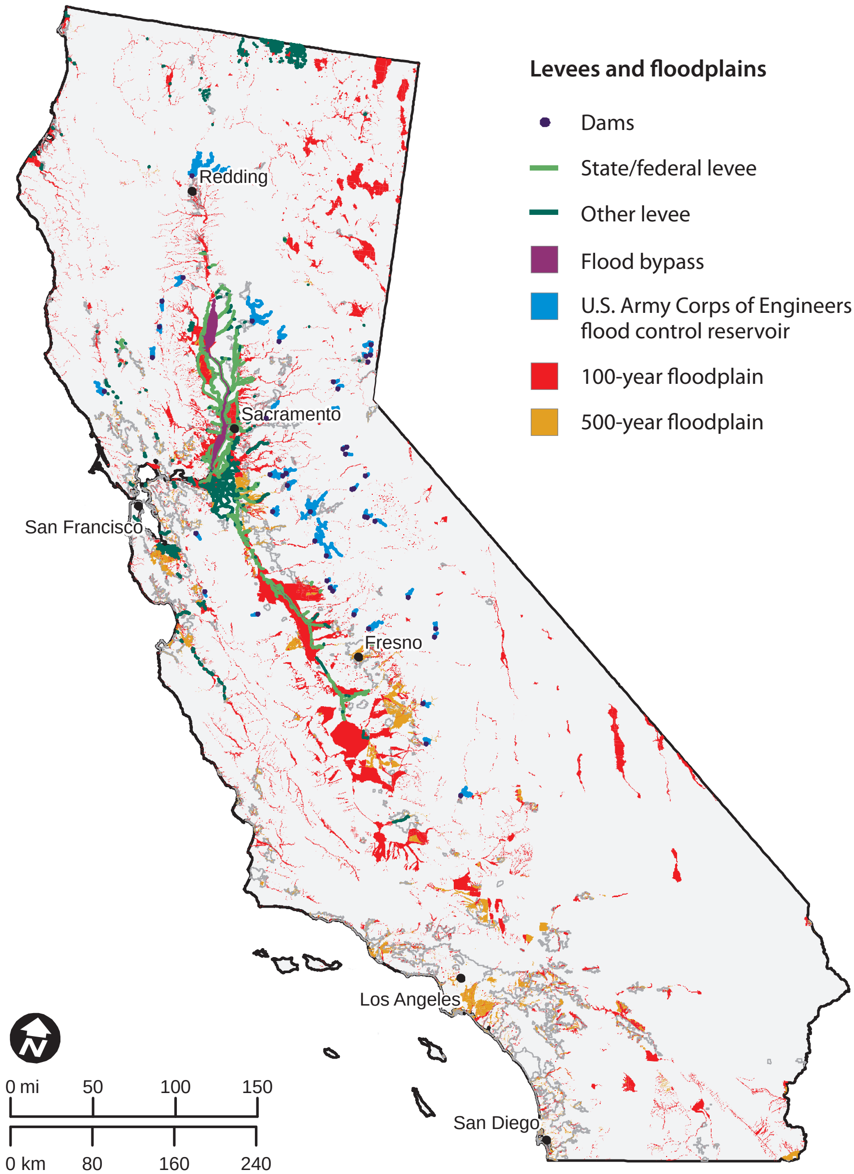
Levees, the most common tool, attempt to limit the area of flooding by containing flows with embankments. Because levees are managed by many diverse public agencies and private individuals, no comprehensive statewide levee inventory exists. The Central Valley alone has as many as 6,000 miles of levees. The Sacramento–San Joaquin Delta and the federally authorized Sacramento–San Joaquin Flood Control projects together have about 2,700 miles of levees. In the Sacramento Valley, levees are supplemented by a system of flood bypasses established in the early 20th century. The bypasses are large areas of seasonal farmland and habitat, bounded by levees, which essentially create a second Sacramento River to accommodate large floods. Upstream reservoirs also help manage floods by storing water to reduce flood peaks that must be accommodated downstream by levees and bypasses.

In 2000, almost 5 percent of California's households were living in what is known as the "100-year" floodplain—an area susceptible to more frequent floods, where land use is regulated by federal flood policy and where federal flood insurance is required (Chapter 6).[30] Another 12.5 percent of households lived in the "500-year" floodplain, an area susceptible to larger, less frequent floods that have a 0.2 percent or more chance of occurring in any given year.

29. The adaptability of hydropower to changes in climate and water management purposes has been widely examined (Jacobs et al. 1995; Madani and Lund 2009, 2010; Tanaka et al. 2006; Vicuna et al. 2008).

30. Authors' calculations, using Census 2000 block data for household population and floodplain designations from the Federal Emergency Management Association.

Figure 2.13
California relies mostly on levees, flood bypasses, and reservoirs for flood protection



SOURCES: For levees, reservoirs, and bypasses, California Department of Water Resources; for floodplains, Federal Emergency Management Agency.

NOTES: The map does not show all locally managed levees; it shows only flood reservoirs overseen by the U.S. Army Corps of Engineers. It shows two of the largest flood bypasses—Yolo Bypass and Sutter Bypass. Urban areas are outlined in gray.

Under federal law, homes in these areas are not required to have flood insurance, and land use is not regulated. Levees protect many homes that would otherwise be located in the 100-year floodplain. Flood insurance subscription in California is low. In 2006, just over 30 percent of the households in the 100-year floodplain had flood insurance and just 7 percent of those within the 101 to 500-year floodplain had insurance.[31]

Overall, this system protects most of California's Central Valley from the most frequent floods, with the exception of parts of the Delta. Parts of Southern California, the California coast, and local streams in Northern California have recurrent localized flooding problems, as evidenced by the number of federally declared flood disaster events since the late 1970s (Figure 2.14). For large floods, which occur only a few times per century on average, many parts of the state face much greater challenges. The Sacramento area, in particular, has been singled out as having some of the weakest flood defenses of any major metropolitan area in the country, well below New Orleans—a fact not missed by California's media and policy community following Hurricane Katrina's devastation of New Orleans.[32] A large flood in the Sacramento area would put thousands of lives at risk and lay waste to tens of billions of dollars in property damage.[33]

Hurricane Katrina brought renewed attention to flood risks and flood infrastructure in California, the poor state of many levees, the growing numbers of residents living in areas with high flood risk, and the potential for increasing flood risk with climate change (Chapter 1).[34] In 2005, federal authorities began requiring testing and recertification of all levees in communities that wish to maintain access to federal flood insurance, resulting in the downgrading of

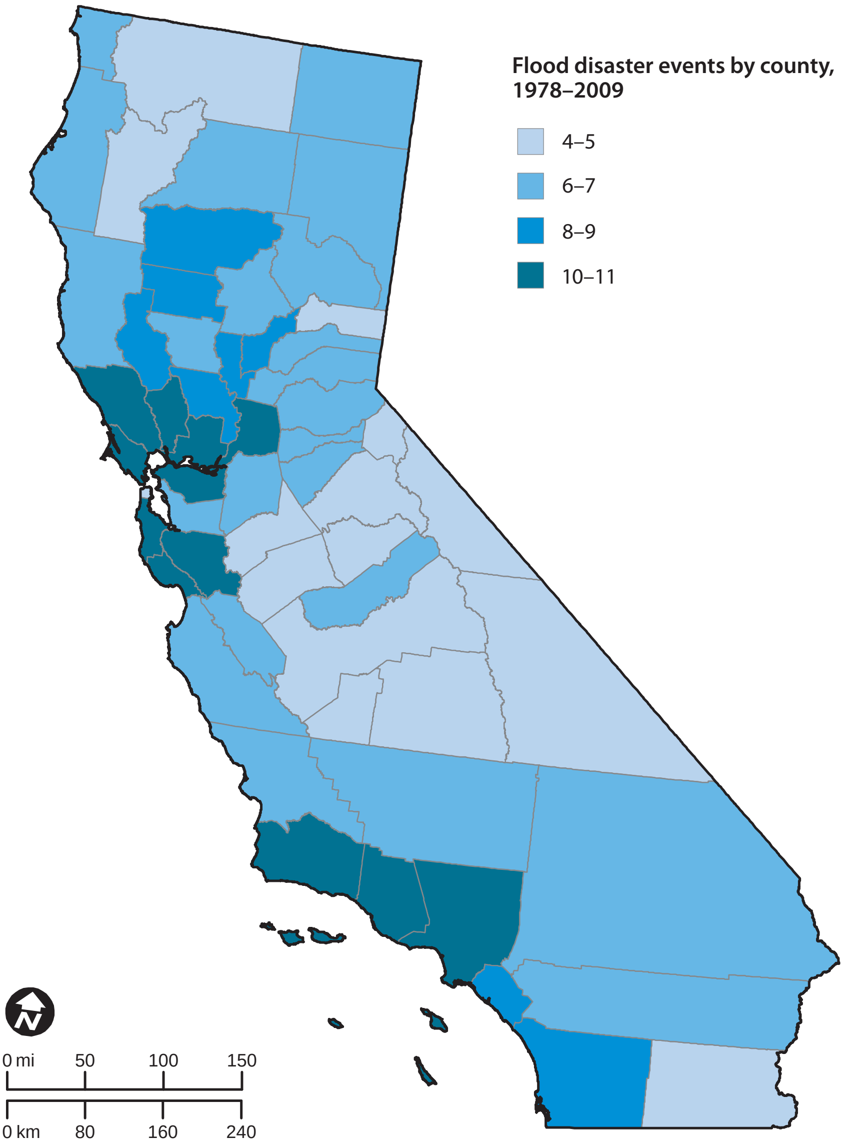
31. Authors' calculations using estimates of households in floodplains (see the preceding footnote) and data on insurance by zone for California's communities from the Federal Emergency Management Agency. In contrast, over 80 percent of U.S. homes have fire insurance, a hazard that strikes about 0.3 percent of homes per year (a 1-in-330 chance per year) (authors' calculations using data from the National Fire Protection Association (www.nfpa.org), the National Association of Insurance Commissioners (www.naic.org), and the U.S. Census). California fire insurance coverage and fire frequency rates appear roughly similar to these national averages.

32. On August 31, 2005, a *Sacramento Bee* article titled "New Orleans flooding 'wake-up call' for capital" gave an early diagnosis: "Levee failures . . . [are] a chilling reminder that the two cities have a lot in common" (Weiser 2005). The website of the Sacramento Area Flood Control Agency (SAFCA) depicts a graphic comparing the flood risk of Sacramento with that of a number of other major cities, including New Orleans (www.safca.org/floodRisk/floodThreat.html).

33. In the area managed by SAFCA (the City of Sacramento and part of Sacramento County), property losses from flooding are projected to be close to $20 billion in 2019 (Sacramento Area Flood Control Agency 2008), and many other communities are at high risk of flooding at the same time, including West Sacramento, Yuba City, Marysville, and surrounding areas. Ongoing efforts to upgrade SAFCA levees are likely to reduce the likelihood of flooding from about 1.5 percent per year to about 0.5 percent per year (www.safca.org). But Sacramento will still face large residual risks (defined as damage times likelihood) of more than $90 million per year. Moreover, in some low-lying areas such as Natomas, levee failures could still put many lives at risk.

34. The California Department of Water Resources (2005a) issued a white paper on the coming flood crisis in January 2005, months before Katrina, and the Federal Emergency Management Agency issued its order for levee recertification a week before Katrina. But both state and federal policy attention was clearly galvanized by the devastation caused by the hurricane.

Figure 2.14
Flooding affects many parts of California



SOURCE: Authors' calculations using data from the Federal Emergency Management Agency.

some levees and reclassification of some areas as within the 100-year floodplain. In 2006, state voters approved nearly $5 billion in bonds to fund flood system upgrades, and in 2007, the state legislature passed, and the governor signed, a set of flood policy bills to raise the level of flood protection in urban areas and reduce new development in high-risk areas. Although this renewed attention to flood protection is valuable, more fundamental policy shifts are needed to protect California's residents from harm and to improve the environmental performance of flood infrastructure (Chapters 5, 6).

Water System Management and Finance

In the United States, most water management is local, and California is no exception. Although state and federal legislatures, agencies, and courts have roles in all aspects of water management, thousands of local entities have the frontline responsibility for serving customers, complying with water quality regulations, and raising revenues to cover the operations, maintenance, and capital investments needed to support these tasks. The governance of water in California also involves many nongovernmental interest-based organizations and many large and small private groups, including business interests and ultimately the general public, which make water-related decisions in homes, in businesses and farms, and at the ballot box. In this section, we review the primary roles of different players in managing water, including their opportunities to improve their management and their principal constraints—financial and otherwise. We begin with local decisionmakers (the most numerous and important group) and proceed to state, federal, and other groups involved in managing California's water.

An "Adhocracy" of Decentralized Decisionmakers

Although the federal and state governments played a major role in large-scale water infrastructure development, California's water system remains highly decentralized, with roots dating back to the Era of Local Organization in the late 19th century (Chapter 1).[35] Well over a thousand specialized and general purpose local governments, water companies, and other organizations manage water locally (Table 2.6). Several dozen wholesale utilities sell water to other water agencies, and roughly 400 large retail utilities (those serving at least 3,000

35. This reality contrasts with traditional views of water management in the western United States, which emphasize the role of the state and especially federal governments (e.g., Worster 1985).

Table 2.6
Principal types of local water management agencies

Agency	Responsibility
Urban water and wastewater utilities (city departments, special districts, and private utilities)	Urban water supply, wastewater treatment
Agricultural water agencies (irrigation districts, other special districts, mutual water companies)	Agricultural surface water supply (sometimes also management of groundwater recharge and conjunctive use)
County flood control agencies and reclamation districts	Local flood management, including maintenance of federally authorized levees
Groundwater management entities (water masters, special districts)	Local groundwater basin management for adjudicated basins and special groundwater management areas
City and county governments	Land use permitting and stormwater management
Resource conservation districts	Land and water use management for habitat improvements
Power utilities (private utilities, urban and agricultural water agencies)	Hydroelectric projects

NOTES: For details on special districts, see Special Districts Annual Report Fiscal Year 2007–08, Appendix B: Number of Special Districts by Type and Governing Body (www.sco.ca.gov/Files-ARD-Local/LocRep/0708specialdistrictosp.pdf). For a list of California water districts, see www.lib.berkeley.edu/WRCA/district.html. And for a digital repository of California water district documents, see http://webarchives.cdlib.org/a/CAWaterDistricts.

customers) deliver water to most California homes and businesses.[36] Several thousands more serve smaller, more rural communities. Several dozen public entities oversee adjudicated and other specially managed groundwater basins (primarily in Southern California) (Chapters 4, 6). Hundreds of agricultural water districts supply surface water to California's farmers. Nearly 600 local wastewater utilities are responsible for meeting Clean Water Act standards in discharging municipal waste. Many of California's county governments and numerous special districts oversee local flood management programs. Over the past decade, many city and county governments have become responsible for the quality of stormwater runoff under the CWA. These local governments—538 in all—also have principal responsibility for local water-related land use decisions and local codes, which affect water demands, flood vulnerability, and stormwater flows.[37] Along with the state and federal water projects, various

36. These are the utilities required to comply with the Urban Water Management Planning Act. See Hanak (2005b, 2010).

37. Local decisions on the location of development are especially important for flood risk management and source-water protection. Local ordinances and codes on outdoor landscaping and stormwater capture are important for water conservation and water quality.

local and regional public and private entities manage over 150 hydroelectric facilities. In some areas, local resource conservation districts are charged with overseeing ecosystem-related land and water management.

This institutional diversity creates the potential for innovation and flexible responses to management challenges, but it can also limit the scope for effective coordination (Bish 1982). Coordination can be particularly important—indeed necessary—when water management involves multiple functions, or when the scope of management is geographically defined. For instance, water and wastewater utilities need to collaborate to effectively manage recycled wastewater programs, and significant problems can occur if land use authorities do not coordinate with water suppliers, wastewater utilities, and flood management agencies when making zoning and land-use-permitting decisions. Coordination at the level of groundwater basins is required to limit problems of groundwater overdraft, and broader watershed coordination can create benefits that cut across institutional lines (e.g., recharging aquifers with stormwater to augment water supply and limit polluted runoff from entering local streams). Coordination also can enable local entities to realize scale economies in some activities.

Some of California's local water management entities already benefit from structures that facilitate coordination. For instance, a few agencies manage both water supply and floods, and about 40 percent of water utilities also treat wastewater.[38] About 70 percent of large urban water utilities belong to wholesale networks, the largest of which—the Metropolitan Water District of Southern California—indirectly serves roughly 18 million of the state's residents.[39] Utilities that jointly manage water and wastewater and members of wholesale networks produced significantly better urban water management plans than utilities not benefitting from this integration (Hanak 2009a). The physical linkages and institutional arrangements within wholesale networks also can significantly improve the capacity to respond to supply shortfalls. Many Southern California utilities are also linked through their membership in adjudicated basins, supervised by court-appointed water masters who oversee water supply and use; such adjudications facilitate the trading of supplies.[40]

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38. Estimates on the share of joint water and wastewater utilities are from Hanak (2005b). Examples of agencies that provide both water supply and flood control functions include the Yuba County Water Agency and the Santa Clara Valley Water District.

39. Estimate on the share of retail utilities within wholesale networks is from Hanak (2005b).

40. For instance, sales of water between members of the Mojave Basin and several other Southern California adjudicated basins are common (*Water Strategist*, various issues).

The value of coordination is spurring the expansion of new forms of formal and informal cooperation. Joint powers authorities are becoming a popular mechanism to allow agencies to conduct joint investments and operations in areas such as watershed and groundwater basin management.[41] The past 15 years also have seen the rise of groups engaged in groundwater management planning and regional water planning, encouraged in part by the availability of state bond funds for these activities (Chapter 6).[42] In addition, state laws (Senate Bill [SB] 610 and SB 221, passed in 2001) now require local land use authorities to coordinate with water utilities before approving large urban development projects (more than 500 units) to ensure that long-term supplies will be available (Hanak 2005b, 2010). As part of the 2007 flood legislation, local governments in the Central Valley will soon be required to incorporate flood risk considerations in their general plans and establish community protection goals (AB 162). This progress notwithstanding, more systematic efforts will be needed to coordinate and integrate water management activities at the basin and watershed scale to effectively address growing water supply, flood, water quality, and ecosystem management challenges (Chapters 5, 6, 8).

State and Federal Roles in a Decentralized System

Although day-to-day management of California water is highly decentralized, federal and state authorities from all three branches of government set the overall policy framework and regulatory context for local entities. Congress and the state legislature are the ultimate policymakers, but a range of federal and state agencies have considerable regulatory authority over water policy, planning, and operations. The judicial branch's role in resolving legal disputes makes it a critical arbiter of many controversial issues.

Legislatures

Congress and the California legislature have been responsible for numerous large and small water policy decisions and directives. As described in Chapter 1, the federal Flood Control Act of 1928 brought major changes to flood management policy, and state legislative and congressional approval of the Central Valley Project in the 1930s and the State Water Project in 1959 set the stage for the

41. Examples include the Santa Ana Watershed Project Authority (watershed management, including the operation of a brine line) (Chapter 6), the Sacramento Regional Water Authority (groundwater management within the Sacramento area) (www.rwah2o.org/rwa/), and the Orange County's Groundwater Replenishment System, noted above.

42. Hanak (2003) provides information on multiagency groundwater management planning entities formed under Assembly Bill (AB) 3030, adopted in 1992.

development of the large interregional water projects that form the backbone of California's water infrastructure. State and federal environmental laws enacted beginning in the late 1960s have fundamentally reshaped the context of almost all water management decisions. The absence of legislative action has also left its mark. Notably, the failure of California's legislature to include groundwater in the modern Water Code in 1913 and its subsequent failure to regulate groundwater have resulted in the fragmented and often ineffective management of this resource.

Over time, state legislation also has shaped the institutional framework of California's decentralized water management system by establishing the authority of cities, counties, and the various forms of special districts that operate in California (Chapter 1; Hundley 2001). Over the past three decades, most state water legislation has sought to require or facilitate action by these decentralized entities (Table 2.7). A variety of laws aim to improve local planning and coordination, and some impose conservation efforts on local entities. In the 1980s, a suite of laws was enacted to facilitate the transfer of water between local agencies and water users through water markets. Beginning in the early 1990s, a series of laws mandating the use of low-flow plumbing devices and appliances have also targeted water conservation by end users. Although local districts often object to such measures, state-imposed requirements can make it easier for them to withstand local opposition. For instance, 2004 legislation requiring that all utilities install water meters and begin billing by the amount of water used targeted many unmetered Central Valley communities, where local opposition to metering had prevented reform.

These laws have facilitated incremental improvements in water management at the local level. In recent decades, however, the legislature has had less success instituting broader changes that will be necessary to meet future management challenges. For instance, two laws enacted as part of the 2009 water policy package—on groundwater monitoring and on water rights enforcement—addressed crucial areas of reform but were significantly watered down in response to opposition from local stakeholders.

Administrative agencies

Over time, state and federal legislation has also established state and federal agencies concerned with different aspects of California's water system (Table 2.8). These agencies regulate and support the actions of local entities, and many also manage large water supply, flood, and environmental management projects. Some state and federal agencies also collect and analyze data to improve the technical and scientific basis for decisionmaking.

Table 2.7
Major state water legislation since 1980

Year	Legislation
1980	Water transfer legislation Conservation for water transfers is a beneficial use of water Third-party protections against harm from water transfers extended to fish and wildlife
1983	Urban Water Management Planning Act, requiring large urban suppliers to develop long-term water plans (amended numerous times since to incorporate additional elements and require coordination)
1986	Agricultural Water Management Planning Act, requiring agricultural districts to develop water conservation plans Water transfer legislation: DWR directed to encourage and facilitate water transfers "Wheeling" statute, providing for the conveyance of water through unused aqueduct capacity
1991	Water Recycling Act, establishing a statewide goal for reclaiming wastewater Water transfers authorized for environmental uses
1992	Formation of groundwater management districts and the adoption of local groundwater management plans authorized (AB 3030) Low-flow plumbing fixtures required in new construction (toilets, showers) (updated in 2007)
1999	Water transfer legislation: Expedition of short-term transfers and increased protection of water rights (Model Water Transfer Act)
2001	"Show me the water" laws (SB 210 and 610), requiring that local governments verify long-term water availability for new development with local water suppliers
2004	Urban utilities required to meter water and bill by volume used
2006	Urban outdoor water use conservation: Outdoor sprinklers required to meet water efficiency standards Cities and counties required to prepare local landscape ordinances
2007	Central Valley flood control package: 200-year flood frequency protection required for new urban development General plans and zoning ordinances required to comply with state plan of flood control Local governments responsible for some flood liability for new urban development (shared with state) Annual notification of landowners protected by levees
2009	Water policy package: New governance structure for the Sacramento–San Joaquin Delta and the development of a Delta Plan based on the co-equal goals of ecosystem protection and reliable water supplies; recognizing reasonable use and the public trust as the foundation of California water resources management (SB X7-1) Submission of $11.1 billion water bond to voters (SB X7-2) Local agencies required to monitor the elevation of groundwater basins (SB X7-6) Urban water agencies required to reduce per capita water use by 20 percent by 2020 and agricultural water agencies required to develop new water management plans and impose water charges based at least partly on quantity delivered (SB X7-7) More resources for water rights enforcement (SB X7-8)

Table 2.8
Primary state and federal water management agencies

Agency	Responsibility
State	
State Water Resources Control Board	Permits and administers state surface water rights; regulates water quality (along with nine regional boards)
California Department of Water Resources (California Natural Resources Agency)	Administers the State Water Project; oversees state flood control operations and overall state water planning
California Department of Fish and Game (California Natural Resources Agency) and Fish and Game Commission	Implements California fish protection laws and the state Endangered Species Act
California Department of Public Health	Regulates drinking water quality (utilities, devices)
Central Valley Flood Protection Board	Permits construction and modification of levees within the Central Valley
California Public Utilities Commission	Regulates water rate structures for private water utilities (~20 percent of urban customers)
Federal	
U.S. Department of the Interior	Acts as watermaster for the Colorado River
U.S. Bureau of Reclamation (USBR) (U.S. Department of the Interior)	Administers the Central Valley, Klamath River, Colorado River, and other projects
U.S. Fish and Wildlife Service (U.S. Department of the Interior)	Administers the federal Endangered Species Act for inland fish species
National Marine Fisheries Service National Oceanic and Atmospheric Administration (U.S. Department of Commerce)	Administers federal Endangered Species Act for salmon, steelhead trout, and other species that spend at least part of their lives in the ocean
U.S. Environmental Protection Agency (EPA)	Regulates water quality through the Clean Water Act, Safe Drinking Water Act, Resource Conservation and Recovery Act, and other federal laws
U.S. Army Corps of Engineers (U.S. Department of Defense)	Builds and oversees flood control systems and flood operations of most reservoirs
Federal Emergency Management Agency (U.S. Department of Homeland Security)	Operates the National Flood Insurance Program (including levee certification and regulation of land use in floodplains) and provides flood disaster assistance
Federal Energy Regulatory Commission (FERC)	Licenses and regulates dams that produce hydropower

Some of the same coordination challenges found at the local level occur at the state and federal levels as well. For example, through an accident of history, two different federal agencies, housed in separate cabinet departments, administer the Endangered Species Act for different fish that live within the same inland water systems. Through another accident of history, the federal government owns and operates the Central Valley Project, which shares the Delta as a conveyance hub and runs parallel to the state-run State Water Project for much of its length (Chapter 1). Although USBR and DWR work together on operations under a Coordinated Operating Agreement, differences in CVP and SWP rules and distinct water rights have complicated water transfers between users on either side of this administrative line. Coordination is also necessary, and often difficult, between the state and federal agencies that operate water supply infrastructure and the U.S. Army Corps of Engineers, in charge of flood control operations in most reservoirs. Coordination gaps among these and other agencies operating in complex systems, such as the Delta, were one of the impetuses behind the CALFED process in the mid-1990s, which formed numerous interagency working groups (Chapter 1; Little Hoover Commission 2005). The Delta Stewardship Council, created under the 2009 legislative package, is another attempt to resolve coordination problems, this time by centralizing some planning functions at the level of a seven-member appointed council. As discussed below, lack of coordination poses particular problems in the conduct of science to support policymaking.

Agencies are often constrained in exercising their authority by staff and funding limitations, which frequently reflect political opposition to action. This has been a particular challenge for state agencies. For instance, water rights administration by the State Water Resources Control Board has been hamstrung by low levels of staffing, resulting in multidecade backlogs in processing water rights applications in such areas as the Russian River (Little Hoover Commission 2010). In the past, the board also has been criticized for failing to exercise its wide latitude to place restrictions on the exercise of water rights for the benefit of the public interest.[43] The Department of Fish and Game, which has broad authority to regulate dams and water diversions to protect aquatic species under the Fish and Game Code, faces even greater challenges related to staffing, resources, and lack

43. In 1986, for example, the California Court of Appeal criticized the State Water Resources Control Board's failure to more aggressively address water quality issues in the Delta. According to the court, the board overlooked its "statutory commitment to establish objectives assuring the 'reasonable protection of beneficial uses,'" which "grants the Board broad discretion to establish reasonable standards consistent with overall statewide standards" (*United States v. State Water Resources Control Board [Racanelli]* 1986). More generally, see Hundley (2001).

of political clout. Critics of the Department of Water Resources express concern that the agency's broader public mission of statewide water resource planning conflicts with (and is compromised by) its operation of the State Water Project (Little Hoover Commission 2010). In Chapter 8, we suggest some institutional reforms to improve the performance of these state agencies.

Federal agencies also face resource constraints, exacerbating the effects of diminished federal involvement in California water in recent decades (Chapter 1). In particular, the ability of the U.S. Army Corps of Engineers to play a major role in California has been severely taxed by American involvement in wars and reconstruction in Iraq and Afghanistan, as well as the need to focus domestic efforts on the Gulf of Mexico in the aftermath of Hurricane Katrina and the British Petroleum oil spill.

The courts

California's judicial system also plays an important role in water governance, with the courts serving as arbiters of disputes over particular water management and use issues that often affect or reflect broader policies. State courts, rather than the legislature, established the initial contours of California's hybrid system of water rights, and courts continue to define and redefine those contours (such as the meaning of "reasonable use") (Gray 2004). In the absence of state groundwater permitting, courts have been the locus of adjudication proceedings for groundwater basins. Federal and state courts also have had a central role in environmental policy. In recent years, court actions have been particularly important in protecting environmental flows and other environmental amenities of water, both through the judicially enforced public trust doctrine (*National Audubon Society v. Superior Court* 1983) and through their interpretation and enforcement of the federal and state Endangered Species Acts (Moore, Mulville, and Weinberg 1996; Doremus and Tarlock 2003). For instance, current controversies over water supply and endangered species management in the Delta are largely being played out in a federal court in Fresno (Chapter 1). The threat of a court decision can also lead parties to come to a settlement—the case with the recent agreement to restore flows to the San Joaquin River to bring back salmon and other fish species (Box 9.1).

A Diverse Mix of Other Actors

Many other groups, both formal and informal, are involved in making and implementing water policies and managing water resources.

Indian tribes and water stewardship

California is home to more than 100 federally recognized Indian tribes and over 200 distinct Indian water allotments, both on reservations and in the federal public domain (Parr and Parr 2009). Under U.S. Supreme Court rulings, these Indian holdings potentially include federal water rights (*Winters v. United States* 1908; Sax et al. 2006).[44] Indian tribes are entitled to as much water as necessary to fulfill the purpose of the Indian reservation, usually enough to irrigate the "practicably irrigable acreage" on the reservation (*Arizona v. California* 1963, 2006). Although the law is not clear, once Indian water rights are quantified, tribes may be entitled to use the water for purposes other than those used to measure the rights—e.g., for environmental flows (Sax et al. 2006).

In contrast to some other western states, Indian water rights have not had a major role in California to date.[45] However, California Indian tribes are interested in the quantification and use of their federal water rights. As Indian tribes seek to quantify and use their water rights, tribal claims could affect existing allocations of water in California. This would be especially true for intrastate allocations of water from the Colorado River, where the U.S. Supreme Court has held that tribal claims may exceed 900,000 acre-feet per year (*Arizona v. California* 1963). Even without greater quantification of their water rights, California tribes sometimes have important roles in California water policy. Northern California tribes, for example, used their fishing rights to help drive the 2009 agreement to remove four dams from the Klamath River (Box 2.4). As holders of Colorado River rights, the San Luis Rey Indians of Southern California helped enable the transfer of water from the Imperial Irrigation District to the San Diego County Water Authority.[46] Indian tribes also have expressed concern about siting infrastructure that may interfere with sacred sites, loss of access to native-resource plants as a result of water activities, the effect of abandoned mines on water quality, illegal diversions, flood planning

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44. Federal water rights enjoy priorities that date to the year the tribal land was reserved from the public domain by executive order or statute, and Indian water rights are not lost by nonuse (*Cappaert v. United States* 1976). The priority date for Indian water rights actually dates to the year in which an Indian reservation was created by treaty, executive order, or statute. No Indian tribes in California, however, are subject to treaties.

45. This is mostly because the water rights of only a few tribes have been quantified (Parr and Parr 2009). In addition, the priority dates for most Indian water rights in California might be late enough to be junior to most existing state water rights. Various legal theories might entitle tribes to earlier priority dates (California Tribal Water Summit Regional Tribal Water Plenary 2009). For experiences in some other southwestern states, see Colby, Thorson and Britton (2005).

46. The tribe and the San Diego County Water Authority are sharing the water savings from the lining of the All-American Canal, one of the components of the Quantification Settlement Agreement noted above. For the time being, the Metropolitan Water District of Southern California is buying the tribe's share until it can put the water to use.

2.4

Indian tribes and the Klamath River

A recent agreement to remove four dams from the Klamath River illustrates the importance of lawsuits and Indian tribes in reforming western water use. The Klamath River once supported the third largest salmon run in the West. The Klamath tribes of the upper basin, as well as the Karuk, Yurok, and Hoopa tribes of the lower basin, relied on salmon and other fish from the Klamath for food, and the salmon runs formed an integral part of their culture. However, six dams built between 1908 and 1962 blocked salmon runs and caused salmon populations to plummet. Despite 19th century treaties guaranteeing them fishing and water rights, the lower basin tribes had to drastically reduce catches, and the upper basin tribes were unable to fish at all. The dams stored water under the federal reclamation program for farmers in south-central Oregon and in Northern California (National Research Council 2004).

When fishermen filed lawsuits against the dam operations under the ESA, the Klamath Tribes filed a brief as amicus curiae. In 2001, a federal court held that these dam operations violated the ESA and enjoined the supply of irrigation water to the farmers (*Pacific Coast Federation of Fishermen's Associations v. National Marine Fisheries Service* 2001). Some farmers resisted the court order by illegally opening headgates, and some men even drove through the Klamath tribes' hometown shooting shotguns. After the bureau resumed irrigation deliveries in 2002, over 30,000 salmon and other fish died from infection, likely brought on by overcrowding in warm, low-flow water (Doremus and Tarlock 2008).

The tribes took advantage of the impending 2006 expiration of several of the dam licenses to push for their removal. They sent representatives to the dam operators and owners and held rallies asking each state's governor to support dam removal. They joined environmental groups in filing a new lawsuit in 2007 against the dam operators and submitted comments during the FERC relicensing process. FERC concluded that license renewal would require the installation of fish ladders and other modifications to allow fish to freely swim upstream past the dams.

By 2005, more than 20 organizations representing the farmers, tribes, salmon fishermen, government agencies, and environmental groups were seeking a negotiated solution. By 2008, the dam operator was also at the bargaining table, having determined that the cost of removing the dams was less than the cost of modifying the dams for fish passage. At a February 18, 2010, ceremony, the major interests signed conditional agreements to study and prepare for the removal of four of the dams—and Governor Schwarzenegger declared "I can see already the salmon are screaming, 'I'll be back.'" The process, however, may take decades before any concrete is moved.

and management that affect tribal lands, and groundwater overdraft. Some tribes have significantly affected FERC relicensing proceedings for hydroelectric projects by identifying traditional cultural properties and Indian trust asset lands within the project vicinity.[47] Tribes also have called for a more active role in regional water planning processes, adjudications, and agreements (California Tribal Water Summit Regional Tribal Water Plenary 2009).

Stakeholder associations

Stakeholder associations representing various interests significantly influence California's water policies. Historically, farm groups, urban water agencies, associations of water agencies and contractors, and environmental organizations have played a leading role, but business, recreation, and community organizations have also often demonstrated their interest.[48] Interest group organizations influence policies and management in various ways, most notably by providing data and information to decisionmakers, lobbying, placing initiatives on the ballot, and initiating lawsuits. Since the introduction of term limits in the California legislature in the early 1990s, stakeholder associations have gained more direct influence on the legislative process, both as a source of expertise and as crafters of legislation (Cain and Kousser 2004).

California residents: water users and ballot box policymakers

As water and land users, the state's residents clearly have an important, direct influence on a range of water policy outcomes. For example, the effectiveness of water conservation incentives, the volume of contaminants that enter storm drains, and the extent of uninsured flood risk exposure all depend on individual actions. The views of the general public also can sway the decisions of legislatures, administrative agencies, and local governments. California residents are also frequently asked to make policy directly at the ballot box, by voting on policy initiatives and approving spending proposals.

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47. Agencies and licensees must take into account the effect of their project on these properties (Federal Energy Regulatory Commission 2004).

48. For instance, in the early 1990s, the Bay Area Economic Forum promoted the development of water marketing. In the mid-1990s, business leaders were also active in negotiations leading up to the Bay-Delta Accord (Chapter 1). In 2001, the California Building Industry Association played an important role in negotiations surrounding the passage of the "show me the water" laws (SB 610 and SB 221) (Association of California Water Agencies 2002). Environmental preservation, recreational fishing, bird-watching, rafting, and other nongovernmental organizations representing specific interests are prominent in California water policy discussions at local, state, and national levels.

Relative to other states, California has an active initiative process, whereby interest groups can put both policy and spending measures on the ballot.[49] In addition, the California legislature must place general obligation (GO) bonds up for public vote, and it has the option to seek voter approval for policy measures. Policy and fiscal initiatives are also common at the local level (Gordon 2004).

Although relatively few policy initiatives have addressed water issues at the state level,[50] the electorate has weighed in on fundamental water policy decisions at several key times in the past: The first modern water code (1914), the Central Valley Project (1933), the "reasonable use" provisions of the California constitution (1928), and the State Water Project (1960) all went before voters for their approval (Chapter 1). Voters were also responsible for two important pieces of recent policy: the 1982 defeat of the peripheral canal, which had been approved by the governor and the legislature two years earlier, and the 1986 passage of Proposition 65, the Safe Drinking Water and Toxics Enforcement Act, which aimed to protect drinking water from several types of hazardous chemicals.

In recent decades, voters have been solicited numerous times to approve GO bonds to support water-related activities. Between 1970 and 2006, voters approved more than 20 water bonds—covering water supply, water quality, and flood control—authorizing a total of over $32 billion (2008 $) in spending (Table 2.9). The size of these bonds has increased dramatically over the past decade, and GO bonds have become a major mechanism for funding state water-related activity. The largest water bond to date ($11.1 billion), part of the 2009 legislative package, was initially scheduled to go before voters in November 2010 and has now been rescheduled for November 2012 over concerns that the economic recession and state budget woes would dissuade voters from approving it.

In parallel to their largesse on state general obligation bonds for water, California voters have directly restricted the financial options of state and local governments, including local water agencies. Proposition 13, passed in 1978, limited property assessments and mandated supermajority voter approval for the passage of local special taxes. California is also one of only eight states with supermajority requirements on the passage of local GO bonds.[51] (State GO bonds require only a simple majority to pass.) For water-related activities, two

49. Out of 24 states that have an initiative process, California was second only to Oregon in the cumulative frequency of initiatives on statewide ballots as of August 31, 2010 (353 vs. 342) (National Conference of State Legislatures 2010).

50. Only 6 percent have addressed environmental issues more broadly (Center for Governmental Studies 2008).

51. This restriction dates back to the early 1900s. Other states with supermajority requirements include Missouri and North Dakota (two-thirds majority to pass local debt) and Idaho, Iowa, Oklahoma, Washington, and West Virginia (three-fifths majority).

Table 2.9
State general obligation bonds for water, 1970–2010

Year	Bond title	Amount authorized (million)		Pass rate
		Current $	2008 $	(%)
1970	Clean Water Bond Law of 1970 (Prop. 1)	250	1,504	75.4
1974	Clean Water Bond Law of 1974 (Prop. 2)	250	1,028	70.5
1976	California Safe Drinking Water Bond Law of 1976 (Prop. 3)	175	606	62.6
1978	Clean Water and Water Conservation Bond Law of 1978 (Prop. 2)	375	1,123	53.5
1982	Lake Tahoe Acquisitions Bond Act (Prop. 4)	85	185	52.9
1984	California Safe Drinking Water Bond Law of 1984 (Prop. 25)	75	150	72.9
1984	Clean Water Bond Law of 1984 (Prop. 28)	325	651	73.5
1984	Fish and Wildlife Habitat Enhancement Act of 1984 (Prop. 19)	85	170	64.0
1986	Water Conservation and Water Quality Bond Law of 1986 (Prop. 44)	150	290	74.1
1986	California Safe Drinking Water Bond Law of 1986 (Prop. 55)	100	193	78.7
1988	California Safe Drinking Water Bond Law of 1988 (Prop. 81)	75	138	71.7
1988	California Wildlife, Coastal, and Park Land Conservation Act (Prop. 70)	776	1,427	65.2
1988	Water Conservation Bond Law of 1988 (Prop. 82)	60	110	62.4
1988	Clean Water and Water Reclamation Bond Law of 1988 (Prop. 83)	65	120	64.4
1996	Safe, Clean, Reliable Water Supply Act (Prop. 204)	995	1,471	62.9
2000	Safe Drinking Water, Clean Water, Watershed Protection, and Flood Protection Act (Prop. 13)	1,970	2,632	64.8
2000	Safe Neighborhood Parks, Clean Water, Clean Air, and Coastal Protection Bond Act of 2000 (Prop. 12)	2,100	2,805	63.2
2002	California Clean Water, Clean Air, Safe Neighborhood Parks, and Coastal Protection Act of 2002 (Prop. 40)	2,600	3,305	56.9
2002	Water Security, Clean Drinking Water, Coastal and Beach Protection Act of 2002 (Prop. 50)	3,440	4,372	55.4
2006	Disaster Preparedness and Flood Protection Bond Act of 2006 (Prop. 1E)	4,090	4,385	64.0
2006	Safe Drinking Water, Water Quality and Supply, Flood Control, River and Coastal Protection Bond Act of 2006 (Prop. 84)	5,388	5,777	53.8
Total		**$23,429**	**$32,442**	

SOURCES: Legislative Analyst's Office (2008); de Alth and Rueben (2005); California Secretary of State.

NOTES: Nominal values were converted to 2008 dollars using the Engineering News Record Construction Cost Index. During this period, one water supply–oriented bond for $380 million ($667 million in 2008 $) was rejected by voters in November 1990 (de Alth and Rueben 2005).

measures are particularly important: Proposition 218, a constitutional amendment passed in 1996, mandated majority or supermajority votes for local general taxes, assessments, and "property-related" fees. Proposition 26, a constitutional amendment enacted in November 2010, raises voting requirements for most state and local regulatory fees—including fees designed to mitigate or remediate environmental harm—from a simple majority to a two-thirds majority.

Proposition 218 has substantially complicated funding for flood control and stormwater programs, which now require direct voter approval to raise funds: a simple majority of property owners, or at least two-thirds of the general public.[52] Although some Sacramento area agencies were able to win high voter approval for new assessments in the wake of Hurricane Katrina, some flood-prone Bay Area communities came up short.[53] Water and wastewater utilities can still raise rates through a vote of their governing boards, although ratepayers can overturn them if a majority protests the increases. However, court interpretations of Proposition 218 are restricting the flexibility of water and wastewater utilities to raise funds to support new development, which can complicate capital project funding (Hanak 2009b). And the courts are also calling into question the ability of groundwater management districts to charge pumping fees without a majority vote of the affected property owners or a two-thirds vote of the electorate (*Pajaro Valley Water Management Agency v. Amrhein* 2007; *Great Oaks Water Company v. Santa Clara Valley Water District* 2010). These decisions are problematic, as groundwater pumping charges are an important tool for managing overdraft.

Proposition 26 affects regulatory fees, which are a natural way to fund environmental mitigation associated with the use of water resources or other activities that impair water bodies. Regulatory fees are typically surcharges on the activity in question, for instance a surcharge on a chemical that causes harm to the environment or public health. Regulatory fees are already used in California to fund programs related to the disposal of hazardous materials and the recycling of oil, among others.[54] Under Proposition 26, regulatory fees with

52. For assessments, the requirement is a weighted majority of property owners. For property-related fees (such as payments for local stormwater control), an alternative to a majority of property owners is a two-thirds majority of the general electorate (Legislative Analyst's Office 1996; Rueben and Cerdán 2003).

53. In 2007, the Sacramento Area Flood Control Agency and the West Sacramento Area Flood Control Agency passed new assessments with 82 percent and 70 percent affirmative vote of property owners, respectively. But in November 2008, the cities of Orinda and Burlingame lost with 62 percent and 64 percent of the popular vote, respectively.

54. See "Official Title and Summary" in the California Voter Guide for the November 2010 election: www.voterguide.sos.ca.gov/pdf/english/26-title-summ-analysis.pdf.

a broad public purpose may now be considered taxes, subject to a two-thirds vote of the state legislature (up from a simple majority). Local governing bodies, which could approve these fees without a vote of the general public, would also be required to seek a two-thirds vote of the general public for such fees. Although the text of the new amendment is uncertain in some respects and will certainly be tested in litigation, Proposition 26 is likely to substantially restrict California's ability to address the current gaps in resources for broad public purposes, including environmental stewardship and water resources planning.

Is There Enough Money to Pay for California's Water System?

Restrictions on state and local funding, along with the budget woes of federal and state governments, naturally raise the question of whether California can maintain, let alone enhance, its current water operations and infrastructure. Water managers in all sectors tend to answer with a resounding "no." But the answer is more nuanced than is commonly believed, reflecting the roles and responsibilities of different levels of government in water system management and differences in funding rules.

Utilities

Urban water and wastewater utilities, which are responsible for the vast majority of spending on water supply and wastewater infrastructure and operations, appear to be in relatively good financial shape. Every four years, these utilities are required to submit estimates of their long-term capital needs to the EPA, which tracks investment needs nationwide. The most recent assessments, from 2007 for water and from 2008 for wastewater, indicate that California's 20-year spending needs for publicly owned utilities are on the order of $40.7 billion and $24.4 billion (2008 $), respectively, or roughly $2 billion and $1.2 billion per year.[55] An additional estimated $3.9 billion over 20 years ($194 million per year) is needed for managing stormwater and nonpoint source pollution, some of which is also handled by wastewater utilities.

In 2007, capital spending by these utilities was substantially higher. According to estimates from the State Controller's Office, publicly owned water utilities invested roughly $3.6 billion and wastewater utilities roughly $2.2 billion (2008 $). (U.S. Census of Governments estimates put total capital outlays for water in

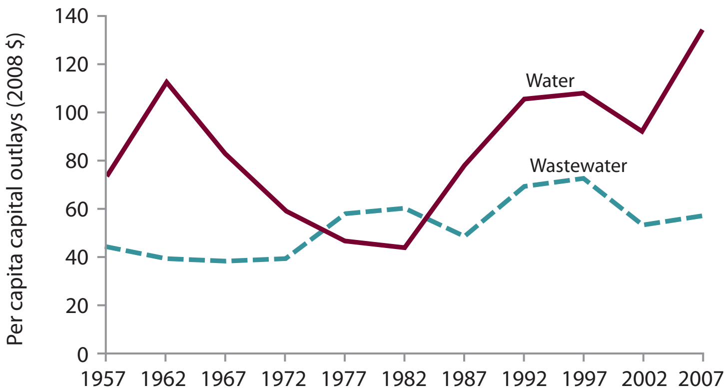
55. U.S. Environmental Protection Agency (2008, 2009). Estimates of both needs and capital outlays reported in the text exclude interest payments.

California even higher, at $5 billion.) For water, these levels of spending reflect increases in real per capita spending since the early 1980s, and for wastewater, a relatively stable rate of spending since the mid-1970s (Figure 2.15).

Although utilities have benefited from state bond funding as well as some property tax receipts, utility revenue comes predominately from ratepayers.[56] Compared with their own estimates of needs, water and wastewater utilities generally appear to have sufficient flexibility to raise rates to fund capital improvements in their systems, although they now face greater procedural requirements arising from Propositions 218. Moreover, water and wastewater rates in California generally fall well within the range considered "affordable" by federal guidelines (less than 4 percent of household income) (Table 2.4).[57] Although raising rates is never easy politically, the ability to raise rates, while

Figure 2.15

Real per capita investments have been rising for water and holding steady for wastewater



SOURCES: Census of Governments; de Alth and Rueben (2005).

NOTE: Nominal values were converted to 2008 dollars using the Engineering News Record Construction Cost Index.

56. In 2007, grants and equity contributions from federal and state sources accounted for less than 2 percent of revenues and contributed capital for all publicly owned local and regional urban and agricultural water agencies and wastewater utilities. Property taxes accounted for 5 percent of urban and agricultural water district revenues and 8 percent of wastewater district revenues; and voter-approved assessments accounted for 6 percent and 2 percent of revenues, respectively (comparable information on the share of tax revenues is not available for city-owned utilities) (authors' calculations using data from the State Controller's Office files).

57. See Hanak and Barbour (2005) for a discussion of affordability guidelines.

maintaining affordability, positions these utilities relatively well for the challenges of upgrading aging infrastructure, a perennial challenge for utilities (Chapter 3).

Flood management

Flood management faces greater financial difficulties. This sector traditionally has relied on federal cost-sharing (typically 65 percent, sometimes higher), and local entities are now subject to public votes for raising local assessments under Proposition 218. Although no comparable exercise exists to estimate statewide flood control spending needs, the Department of Water Resources estimates that the minimum cost of restoring the Sacramento–San Joaquin Flood Control Projects is more than $20 billion (M. Inamine, DWR, personal communication).[58] This estimate does not include upgrading the system to a higher level of protection, as mandated by the new flood legislation passed in 2007, nor does it include flood-related investment needs in other parts of California, many of which are also vulnerable.

In recent decades, federal investments in California flood protection have been modest, leaving Californians to shoulder most of this financial burden. State flood protection funds have come from general obligation bonds ($5 billion from Propositions 1E and 84—see Table 2.9) and other general fund resources (such as emergency levee repair legislation). State bond funding has put California well ahead of the U.S. Army Corps of Engineers, although bond sales were limited by the onset of the recession (Figure 2.16). Over the longer term, the bigger problem will be raising new sources when the bonds are exhausted, given the vast unfunded capital needs. As discussed in Chapter 6, new forms of regional or statewide risk-based assessments or fees will be needed.

Environmental mitigation

Although the estimated funding requirements for environmental mitigation are smaller than those in the flood management sector, the management of polluted stormwater and other types of runoff face similar challenges because of Propositions 218 and 26. City and county governments are required by law to meet Clean Water Act standards regarding these nonpoint sources of pollutants, yet they are required to go to voters to raise the necessary funding—a difficult task when the problems caused by pollution occur downstream rather than close to home (Hanak and Barbour 2005).

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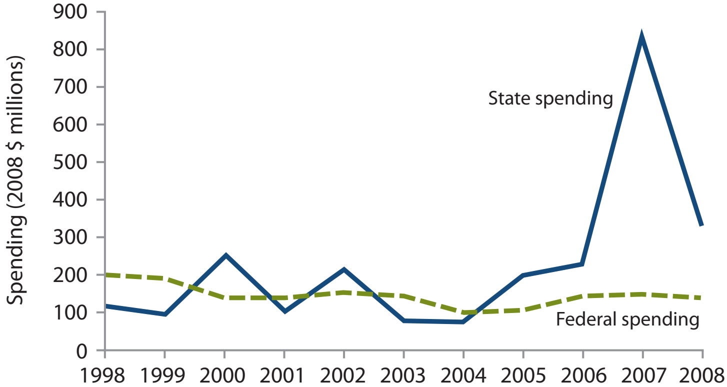
58. For comparison purposes, the *New York Times* reports the cost of levee system reconstruction in New Orleans at $15 billion (Schwartz 2010).

Figure 2.16
The state has surpassed the federal government in flood protection spending in California



SOURCES: U.S. Army Corps of Engineers; governor's budgets.

NOTE: Nominal values were converted to 2008 dollars using the Engineering News Record Construction Cost Index.

Another area of systematic mismatch between funding mechanisms and funding needs is environmental management. California water users pay only for the infrastructure-related costs of water delivery, not the environmental costs of diversions. Although, in principle, new water supply and flood control projects are required to mitigate environmental harm, the cumulative effects of decades of water system development have contributed to the widespread degradation of aquatic ecosystems described in the Introduction. Recent bonds have provided some support to scientific research and habitat investments, but bonds are an unreliable source of funds for these purposes. This is where the new constraints imposed by Proposition 26 will be felt the most. Surcharges on water use and other water-related activities, such as flood infrastructure investments and the discharge of contaminants, are an appropriate way to fund environmental mitigation and the related science needed to redress the decline of California's aquatic ecosystems.

Budget woes

Finally, state budget problems over the past decade have reduced funding for the basic state operations of monitoring, analysis, and enforcement of water policy. Bond funds have provided stopgap funding for activities once supported by the general fund.[59]

California needs more reliable, user-fee based funding to support publicly related water expenses, including the basic science, monitoring and planning functions of government as well as investments to improve aquatic habitat. As discussed in Chapter 7, the state's energy and transportation sectors provide useful user-fee models.

Whether the public can be convinced to shift to more fee-based funding of such public functions is an important question. Voter support for numerous water bonds suggests a willingness to support these activities with taxpayer dollars, but it is not clear that voters recognize the costs of state general obligation bonds in terms of new taxes or reduced spending in other areas. (Indeed, state general obligation bonds are often promoted by their sponsors as *not* requiring new taxes; in contrast, local bonds are generally proposed along with a revenue source to cover the obligation [Hanak 2009b]).

In contrast to such issues as the economy, education, and crime, water is generally not the foremost policy issue on the minds of the state's residents.[60] However, public opinion surveys suggest that the public is concerned with water conditions in the state. Over the past decade, water issues (supply and quality) have generally ranked second after air quality as the state's top environmental issue (Figure 2.17). (Water surpassed air quality in 2009, when many residents faced voluntary or mandatory rationing because of drought conditions and cutbacks in Delta pumping.) In recent surveys, more than two-thirds of respondents said that water supply is at least somewhat of a problem in their region (Baldassare et al. 2009a, 2010). Looking ahead, most said that they are very or somewhat concerned about the potential for more severe floods (55–60 percent) and droughts (78–85 percent) as a result of climate change (Baldassare et al. 2005, 2007, 2009). Although raising new fees to support the water sector is not likely to be popular with California voters, better public information about water system conditions might help foster public discussion for reform of the inadequate funding mechanisms currently available.

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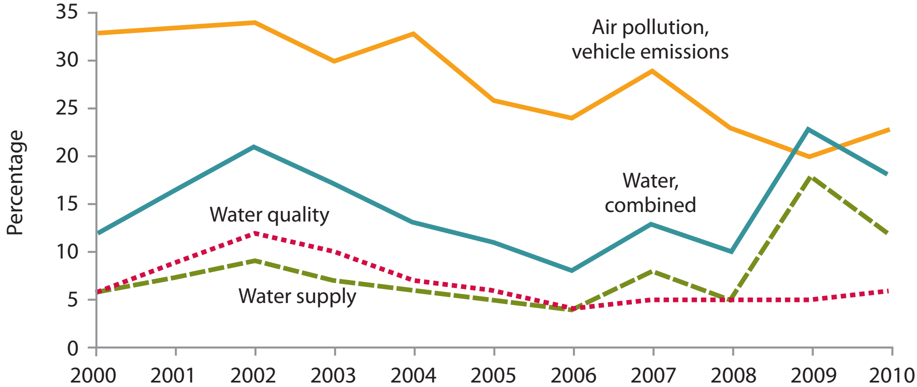
59. Since the onset of chronic state budget problems in 2001, bonds have funded at least one-quarter —and sometimes more than half—of DWR's operational expenses in every year except 2005 (authors' calculations using information from the governor's budgets).

60. In 38 surveys conducted by the Public Policy Institute of California between August 1999 and June 2010, water (supply or quality) never accounted for more than 2 percent to 3 percent of responses to the open-ended question: "Thinking about the state as a whole, what do you think is the most important issue facing people in California today?" Jobs and the economy were almost always the highest, occasionally surpassed by immigration (in 2007), crime (in 2003), energy prices (in 2001), and schools (1999) (all surveys are available at www.ppic.org).

Figure 2.17
Water is one of residents' top environmental concerns



SOURCE: Baldassare et al. (2000–2010).

NOTE: The figure reports the share of residents identifying these issues in open-ended responses to the question: "What do you think is the most important environmental issue facing California today?"

Scientific and Technical Support for Decisionmaking

Effective water management requires sound information, and water management systems as complex and extensive as California's require commensurately broad and well-organized scientific and technical support. The development of the Central Valley Project, the State Water Project, and the Central Valley flood control system all involved focused and systematic development of scientific and technical knowledge and expertise over decades (Chapter 1). The Hydraulic Era in California's water development required tremendous growth in technical expertise in all branches of government and the private sector. From this emerged one of the most complex and effective water supply and flood control systems in the world.

The Era of Conflict stimulated dramatic growth in demand for scientific support for environmental regulations. Setting Clean Water Act standards for flow and pollutant discharge, evaluating mitigation alternatives, constructing wastewater treatment plants, determining the causes of decline of native species subject to the Endangered Species Act, and evaluating the effects of water operations on ecosystems each required advances and organized application of science. Today, California's scientific infrastructure is extensive and diverse. Hundreds of scientists are involved in water management in California at government agencies, at universities, and as private consultants. Yet few would argue that this infrastructure meets current needs, and even fewer would suggest that California is prepared for the next era.

The dramatic changes in conditions that California will face through the rest of the century will require greater synthesis and emphasis on developing solutions, beyond regulatory problems and details (Chapter 3). Science will have a major role in an Era of Reconciliation. Along with its traditional roles of facilitating design and operation of water management, science and technological innovations must facilitate the adaptation of management. Science will be essential for effective strategic and incremental reconciliation of environmental and human water uses, locally, regionally, and statewide, just as engineering science was required for the Hydraulic Era to effectively achieve that era's goals.

A Fragmented, Underfunded System

A recent review by the National Research Council (2010) of the biological opinions that govern operations of the Central Valley Project and the State Water Project pointed out that scientific support for water management in the Delta is weak, poorly organized, and lacking integration. The Little Hoover Commission (2005, 2010) offered similar observations, as has the Delta Vision Blue Ribbon Task Force (2008). Yet the Delta has perhaps the state's *most* organized and best-funded science programs to support decisionmaking. National Research Council reviews of science for Klamath Basin management have had similar findings (National Research Council, 2004, 2008).

It is not enough to simply state that insufficient resources have been invested in science for improving water management. Beyond an almost entirely nontechnical California Water Plan Update developed by the Department of Water Resources every five years or so, there is little to no statewide organization, prioritization, and synthesis of technical and scientific activity applied to water problems. This gap stems partly from the highly decentralized management of water. The tensions between water districts—stemming from perceived competition for resources—and institutional barriers between federal, state, and local agencies have balkanized water science and engineering in California. To illustrate the complexity of this problem, Table 2.10 lists federal, state, and local entities that fund scientific and engineering studies in ecosystem management, water supply/quality, flood management, and water-based tourism/recreation. This list neglects many other agencies with jurisdiction and funding control. A recent summary of agencies with responsibilities in these four areas conducted

Table 2.10
Agencies funding or overseeing scientific research on water

Agency	Ecosystem/ environment	Water supply/ quality	Flood management	Recreation/ tourism
Federal				
Bureau of Land Management	●	●		●
Bureau of Reclamation	●	●	●	●
Coast Guard	●	●		●
Department of Agriculture	●	●	●	
Department of the Interior	●	●	●	●
Environmental Protection Agency	●	●		●
Federal Emergency Management Agency		●	●	
Federal Energy Regulatory Commission	●	●	●	●
Fish and Wildlife Service	●	●		
Forest Service	●	●	●	●
Geological Survey	●	●	●	
National Marine Fisheries Service	●	●		
Natural Resources Conservation Service	●	●	●	
U.S. Army Corps of Engineers	●	●	●	●
State				
Department of Boating and Waterways	●			●
Department of Conservation	●	●		
Department of Fish and Game	●	●		●
Department of Food and Agriculture	●	●		
Department of Health Services		●		
Department of Parks and Recreation	●	●		●
Department of Public Health		●		
Department of Transportation	●	●	●	
Department of Water Resources	●	●	●	
Energy Commission	●	●		
Environmental Protection Agency	●	●		
Flood Management Board	●		●	
Natural Resources Agency	●	●	●	●
State Lands Commission	●	●	●	●
Water Resources Control Board	●	●		
Local				
Cities	●	●	●	●
Counties	●	●	●	●
Flood control districts			●	
Irrigation districts	●	●		
Port authorities	●	●	●	●
Reclamation districts	●	●	●	
Resource conservation districts	●	●	●	
Sanitation districts	●	●		
Water districts	●	●		

SOURCE: Authors' survey of agencies with responsibilities for managing or regulating water.

for the Delta Vision Blue Ribbon Task Force identified more than 100 within the Delta alone, and this was considered an incomplete list. Excessive decentralization has greatly reduced the ability of fragmented scientific and technical activity to provide coherent and consistent advice to policymakers.

In addition, investments in science have not kept up with demands for increasing information and analysis. Federal investments in science for California water through the Bureau of Reclamation, U.S. Army Corps of Engineers, Fish and Wildlife Service, National Marine Fisheries Service, and U.S. Geological Survey have been modest and centered mostly on narrow agency missions and mandates, with little broader synthesis or exploration of strategic solutions to long-term problems. Major construction projects, which provided an overall focus, ended decades ago, and, since then, technical management in these agencies has deteriorated badly. The three state agencies responsible for statewide water management and regulation—Department of Water Resources, State Water Resources Control Board, and Department of Fish and Game—have seen a steady erosion of their technical capacity. California has many universities famous for their extensive and high-quality scholarly water research. But this work is often ad hoc, with little coordination or integration beyond a few efforts at a handful of campuses.

One of the largest concerns regarding California's scientific infrastructure comes from changes in how agencies are staffed. For the last 30 years, a strong political drive has shrunk agency staffing and funding while increasing the scope and complexity of their responsibilities. The result has been a long-term shift from in-house agency expertise to reliance on external, for-profit consulting firms to complete both major and minor initiatives. Many major ongoing studies of water management in California—Bay Delta Conservation Plan, Delta Stewardship Council, State Plan of Flood Control, Delta Risk Management Study, and more—are run by consultants directed by agencies. Although this shift reflects fiscal necessities, the loss of in-house expertise—particularly more senior and experienced technical and scientific managers with deep knowledge of operations or ecosystems—reduces the ability of agencies to be nimble and authoritative in their responses or the management of consultants.

Finally, there is a growing information gap regarding water in the state. Dramatic advances have occurred in technology for monitoring water as it moves through the hydrologic cycle. Monitoring the flow and quality of water is essential for water management today and will become increasingly important for an Era of Reconciliation. Yet cash-strapped federal and state agencies, forced to deal with daily crises, have no program for coordinated development of networks that better account for and analyze water movement and management.[61] Without this information, successful adaptation to changing conditions will be hindered or foreclosed.

Costs of "Combat" Science

The failure to organize, integrate, and fund robust science and technical programs to support decisionmaking imposes a high cost on California. The lack of strong, coherent governmental scientific and technical programs has provoked efforts to attack or augment (depending on one's perspective) existing governmental and academic scientific and technical conclusions. Weak government scientific programs contribute to the proliferation of "combat" science—the selective development and presentation of facts and analysis primarily for the political or regulatory advantage (or disadvantage) of one stakeholder group or agency. When the National Research Council (2004) was asked to review the biological opinions governing the operations of the Klamath Project, the authors of the report were struck by the amount of combat science on the basin and how little trust existed in the science being used to make decisions (Doremus and Tarlock 2008).

The recent dust-up over the role of ammonium in the decline of delta smelt is another example. For several years, concern existed in the scientific community over ammonium in the Delta and its potential to disrupt food webs on which native fish depend. Consultants were hired to help the Sacramento Regional County Sanitation District with press releases and studies claiming that although they are the primary source of ammonium in the Delta, the ammonium poses no problem and the Delta's problems are from downstream water exports (www.srcsd.com). To counter this combat science, a coalition of water contractors, led by the Metropolitan Water District of Southern California, funded a researcher from the University of Maryland with no experience in the Delta who drew a sharply different conclusion, suggesting that the ammonium was *the* cause of the decline of delta smelt and that the exporters were blameless

61. Data-collection efforts are typically fragmented and incomplete. For example, the SWRCB collects annual water use reports from surface water right-holders, but these often bear little relation to actual volumes used, and the exercise neglects groundwater users and many riparian and pre-1914 surface water rights holders. Regional water quality control boards collect a substantial volume of water quality data, but there is little synthesis that would enable the use of these data in basin management. Similarly, DWR had a wide range of data-collection and assessment activities but lacks a coherent technical organization that would allow such data to inform or guide integrated water management at regional or statewide scales.

(Glibert 2010). Such combat science has been noted in other basins outside California (White 1995).

Combat science is an inevitable and occasionally useful aspect of California water management. Yet, the recent increase in political manipulation of science, which is highly effective from political and legal standpoints, is a sign of weak, ineffective governmental science programs. It inevitably leads to a loss of transparency and further loss of trust in the science needed to support effective decisionmaking. Weak governmental technical programs and strong combat science are major reasons why so many water management decisions are decided in the courts rather than at the negotiating table.

A New Approach to Water System Science

Improving the science to support decisionmaking, while reducing the influence of combat science in California water management, will require a sustained, integrated effort by the state and federal governments. This must begin with finding new ways to fund scientific infrastructure so that it is less vulnerable to economic and political cycles. In addition, the programs and agencies conducting the research must increase, retain, and better employ in-house expertise and talent. The state must modernize how it tracks water quality and its ecosystem and human uses. Finally, the state needs more independent means to conduct scientific and technical synthesis, less subject to political influence.

A model for a successful program might be the California Energy Commission's Public Interest Energy Research (PIER) program (www.energy.ca.gov/research/index.html). Funded by ratepayers and overseen by a committee chaired by a commissioner, this program has become the focus of energy-related research and monitoring to support policy throughout California. PIER projects focus on energy research projects unlikely to be funded by utilities or consultants because of the general nature of their results or the innovative technical questions addressed. It is structured as a research, development, and demonstration program, largely shielded from political influence, and has become the center of the state's research regarding climate change adaptation. The PIER program is too new to allow a comprehensive assessment of its overall effectiveness, but its climate change efforts have generated a critical mass of research to support climate change policy discussions. The California Air Resources Board also has an extensive scientific and technical program that may provide a model for the water sector (Little Hoover Commission 2009).

Strengths and Weaknesses in Today's Water System

California's water system today has both impressive assets and significant vulnerabilities. A major asset is the sophisticated physical infrastructure that enables water to be delivered to urban and agricultural demand centers and successfully protects residents from frequent floods. Vulnerabilities in this infrastructure—which threaten water supplies and increase flood risk—include a fragile water supply conveyance hub in the Sacramento–San Joaquin Delta, deteriorating flood control structures, chronic overdraft in some major groundwater basins, and increasing problems of water salinity and other contaminants.

Another major asset is the resilience of California's economy, which has shown an ability to adapt and continue to grow, despite increasing water scarcity. Continued adaptation seems possible, with suitable management and policy changes, given the economy's decreasing reliance on water as a direct input into production, the sizable proportion of agricultural water still allocated to low-value crops, and the large share of urban water now used for landscape irrigation. However, economic adaptation potential is limited by regional economic concerns (which can make agricultural communities reluctant to sell or divert water from lower-value crops) and difficulties of reducing outdoor water use by millions of California households and businesses.

For all their complexity, California's diverse water management institutions also have some strong positive features that can serve the state well in confronting the challenges it faces. The state has many dedicated, highly trained staff working on all aspects of its water system, and their decentralized governance means that water managers are quite responsive to local water user needs. However, this system will fail to satisfy the broader needs of the economy and the environment without better coordination that aligns management oversight with the appropriate geographical scale (e.g., basins and watersheds) and that connects activities across different functional areas to benefit water supply, flood protection, water quality, and ecosystems. Similar challenges of coordination exist among state and federal agencies, which also face resource constraints and limits on their authority. Inadequate technical information and scientific capacity is a particular weakness in California's current institutional landscape. Decentralization, fragmentation, and limited resources to collect and analyze information on water use and to support solution-oriented science by major state and federal agencies have hobbled the state's ability to address the major environmental management challenges of the current era. Such redirection of science will be essential in an Era of Reconciliation.

Finally, although money alone is not sufficient for successful water management, it is necessary. Those parts of the water system that rely primarily on ratepayer contributions—water supply and wastewater utilities—seem relatively well-positioned to meet their investment needs. In contrast, flood management, ecosystem management, and the state's overall strategic planning, monitoring, and technical functions have become dependent on unreliable state general obligation bond funding, often well below the levels needed to sustain adequate efforts. California residents have supported these bonds, while also voting to restrict local funding and state funding through fees on water users. Fiscal reforms are needed to provide the state with the financial capacity to adapt and strengthen water supply reliability and flood protection and to redress its failing aquatic ecosystems.

Despite a history of hard-won successes in managing water, California's water system, designed in the 1930s for a very different economy and society, is showing signs of decay and potential disaster. The state is standing on the edge of a very real crisis as it faces the collapse of native ecosystems, the effects of droughts, threats of widespread flooding, and a conspicuous absence of governmental technical and political leadership and funding.

Today's challenges are likely to become even more acute in the coming decades. As described in the next chapter, a range of natural, physical, economic, and demographic forces will increasingly threaten scarce water supplies and heighten the risk of continuing the ecological and economic deterioration of the state's water system.