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Orchestrating the Management of Water Scarcity, Quality, and Flooding



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The plan is nothing. Planning is everything.

Dwight Eisenhower

Growing demands on California's finite and variable water supplies make scarcity a permanent consideration in water management: Managers will always be preparing for shortages, even in very wet years. Impairments in water quality add another dimension to the problem, raising the costs of treating drinking water and wastewater, damaging farmlands, and threatening native ecosystems. And, despite chronic water scarcity, California is also highly vulnerable to flooding in the wettest years. These problems will increase as California's population and economy continue to grow and the climate changes, and they will become more severe and costly if water is not managed well.

Effective management of scarcity, water quality, and floods will involve the orchestration of thousands of management actions at local, state, and federal levels. Just as orchestral music requires many instruments to be played well in combination to provide greater harmony and broader appeal, orchestrated water management employs different water management instruments to satisfy diverse water management objectives.

This chapter reviews institutions and options available to manage water scarcity, quality, and overabundance to meet current and future challenges, with a focus on the direct human uses of water in the urban and agricultural sectors. The chapter begins with a brief discussion of the idea of portfolio-based planning—a useful way to think about how to combine water management actions for greater effect. We then examine California's use of the diverse set of tools available in each of three areas—supply, quality, and flood management—and look at opportunities to better integrate actions to achieve multiple goals in combination. Throughout this discussion, we illustrate how management will

need to adapt to changing conditions in the natural and physical environment. In particular, we present new modeling results that show how a dry form of climate change and a loss of Delta exports may affect California's economy and how aggressive increases in urban water conservation might help offset some of these costs. We also highlight areas where controversies, tradeoffs, and institutional and legal barriers pose particular challenges for adopting promising actions.

Orchestrating Activities Through Portfolio-Based Planning

Most people are familiar with the use of portfolios in financial management to balance risks and returns through diversification. This concept also has become well accepted in many areas of infrastructure planning and operations, ranging from water to energy (Hobbs 1995; Awerbuch 1993) to transportation (Johnston, Lund, and Craig 1995). The general notion is to employ a complementary mix of options—including supply-side, demand-side, and operational tools—to provide more cost-effective service that is reliable under a wide variety of conditions and able to serve multiple purposes.

Complementarities between some options can reduce costs and increase system reliability. For example, an inexpensive water conservation option may help avoid expensive expansions in supplies (sometimes called an “avoided cost”). But extreme levels of water conservation can be more expensive than judicious use of other water management activities. Similarly, coordinated, or “conjunctive” use of surface and groundwater storage allows surface water purchased cheaply in wet years to be stored underground and retrieved for use in drier years, when surface water is more costly. In these cases, neither option would work as well alone. As with a financial portfolio, it is common for some components to do well when others do poorly. For instance, surface water storage does poorly during long droughts, whereas groundwater is more resilient to droughts. Likewise, recycled wastewater and desalinated seawater are relatively expensive options, but, with significant prior investment, they are available even under extreme drought conditions.

Reliance on a variety of management techniques makes systems more stable when faced with such operational disturbances as droughts, floods, adverse legal rulings, and mechanical breakdowns. It also makes them more resilient to

longer-term planning and policy uncertainties from changing climatic, population, economic, and regulatory conditions.

The Water Supply Portfolio

Table 6.1 lists many of the options available to water managers seeking to balance supplies and demands. Options for expanding usable supplies include both traditional methods, such as surface storage, conveyance, and water treatment, as well as more contemporary methods, such as improvements in operational efficiencies, conjunctive use of ground and surface waters, stormwater capture, and wastewater reuse. Keeping water usable by protecting water sources from pollutants is another tool receiving attention. Water demand management options include improvements in water use efficiency (e.g., low-flow plumbing fixtures and irrigation techniques to get “more crop per drop”), as well as reductions in water use below desired levels (denoted here as “shortages”). Often, some amount of shortage is less expensive than the cost of additional supply. Various general tools (pricing, water markets, taxes and subsidies, water markets, and public education) can motivate water users and water agencies to implement both supply- and demand-side options.

Each option provides different benefits, and each entails costs (Table 6.2). The financial costs of most options vary considerably depending on location and water availability conditions. For instance, local water transfers in Northern California agricultural areas can make some water available for \$50 per acre-foot or less, but farmers south of the Delta during the recent drought were paying \$500 or more for some water used by high-value crops. Similarly, cost ranges for new supply facilities, such as surface storage or recycled water, depend on the specific opportunities at different locations. Only a few options—such as low-cost water transfers, some agricultural efficiency measures, some conjunctive use, and conserving water by fallowing—are viable alternatives for most farming activities. Urban water agencies are more likely to employ a wider range of options, even though some options are costlier than many existing, but finite, supplies.¹

1. Water utilities typically face supply costs (not counting treatment and delivery to customers) in the range of \$100 to \$650 per acre-foot (af), though, as noted in Chapter 3, these costs are rising for many reasons. Utilities that pump local groundwater typically have lower supply costs than those using surface water transported over long distances. In 2010, wholesale costs for untreated water from the Metropolitan Water District of Southern California, which now uses tiered rates to encourage member agencies to conserve and develop local sources, were \$484/af for the first tier and \$594/af for the second tier. Wholesale rates for untreated water from the San Diego County Water Authority, a member of Metropolitan, were approximately \$650/af. Wholesale rates from the San Francisco Public Utilities Commission, which sells water to many Bay Area utilities, were approximately \$825/af.

Table 6.1
Water supply system portfolio options

Demand and allocation options
Urban water use efficiency (water conservation)*
Urban water shortages (permanent or temporary water use below desired quantities)*
Agricultural water use efficiency*
Agricultural water shortages*
Ecosystem demand management (dedicated flow and nonflow options)
Ecosystem water use effectiveness (e.g., flows at specific times or with certain temperatures)
Environmental water shortages
Recreation water use efficiency
Recreation improvements
Recreation water shortages
Supply management options
Expanding supplies through operations (affecting water quantity or quality)
Surface water storage reoperation* (reduced losses and spills)
Conveyance facility reoperation*
Cooperative operation of surface facilities*
Conjunctive use of surface and groundwater*
Groundwater storage, recharge, and pumping facilities*
Blending of water qualities
Changes in treatment plant operations
Agricultural drainage management
Expanding supplies through expanding infrastructure (affecting water quantity or quality)
Expanded conveyance and storage facilities*
Urban water reuse (treated)*
New water treatment (surface water, groundwater, seawater, brackish water, contaminated water)*
Urban runoff/stormwater collection and reuse (in some areas)
Desalination (brackish and seawater)*
Source protection
General policy tools
Pricing*
Subsidies, taxes
Regulations (water management, water quality, contract authority, rationing, etc.)
Water markets, transfers, and exchanges (within or between regions/sectors)*
Insurance against drought
Public education

NOTE: Options represented in the CALVIN model (see the text) are denoted by an asterisk.

Table 6.2
Operational characteristics and cost ranges for some portfolio options

Method	Operational pros and cons	Illustrative cost range (\$/af)
Demand and reallocation		
Water transfers	Pros: Flexible tool for lowering costs of dry-year shortages and enabling long-term reallocation of supplies as economy shifts Cons: Potential economic harm to selling regions	50–550
Agricultural water use efficiency	Pros: Reduces total stream diversions and pumping; enables farmers to raise yields and limit polluted runoff. Cons: May not generate net savings that make water available for other users; net use reductions often require fallowing (Box 2.1)	145–675 (per acre-foot of net use reduction)
Urban water use efficiency	Pros: Savings can often occur without loss of quality of life; high net savings possible in coastal areas and with landscape changes; some actions also save energy Cons: Requires implementation by large numbers of consumers; can be especially difficult for outdoor water uses, which depend on behavior as well as technology	225–520 (per acre-foot of gross use reduction)
Supply management		
Conjunctive use and groundwater storage	Pros: Flexible source of storage, especially for dry years Cons: Slower to recharge and harder to monitor than surface storage	10–600
Recycled municipal water	Pros: Relatively reliable source in urban areas Cons: Public resistance can preclude potable reuse	300–1,300
Surface storage	Pros: Flexible tool for rapid storage and release Cons: Potential negative environmental impacts; small value of additional storage with a drier climate	340–820+ (state projects)
Desalination, brackish	Pros: Can reclaim contaminated groundwater for urban uses Cons: Brine disposal can be costly	500–900
Desalination, seawater	Pros: “Drought-proof” coastal urban supply tool, especially useful in areas with few alternatives Cons: Potential environmental costs at intakes and for brine disposal; sensitive to energy costs	1,000–2,500

SOURCES: Water transfer cost data are from the authors’ estimates; cost data for the surface storage low estimate (Sites Reservoir), agricultural and urban use efficiency, recycled municipal water, and desalination are from the California Department of Water Resources (DWR) (2009); conjunctive use cost data are from the California Department of Water Resources (2005b); the cost data for the surface storage high estimate (Temperance Flat Reservoir) are from the authors’ calculations using estimates in U.S. Bureau of Reclamation (2008).

NOTES: Costs are illustrative and vary widely with local conditions. For conjunctive use, the costs of water for banking may be additional. For most options other than water use efficiency, cost estimates do not include delivery. For water transfers, conjunctive use, and surface storage, cost estimates do not include treatment. For agricultural use efficiency, cost estimates are for subsidies needed to implement measures that are not locally cost-effective and refer only to actions yielding net water savings. Many costs from DWR sources are from studies in the early to mid-2000s and may have increased with inflation. Some figures are rounded.

In some cases, it will be less expensive to endure temporary or even permanent shortages than to provide additional supplies. However, planned shortages can be controversial, particularly when water users had more abundant supplies in the past. The controversies are especially intense when agricultural or urban users' supplies are cut for reallocations of water to the environment. But environmental water users have tended to face disproportionately high shortages during droughts, with cuts of 50 percent or more relative to wet years, versus 10 to 30 percent for agricultural and urban users (California Department of Water Resources 2009 public review draft).

Orchestration will often be more effective at the regional scale. When local agencies within a region coordinate their activities, they can benefit from economies of scale for some investments and create a more balanced portfolio. Coordination at the watershed and basin level is required for some tools to be effective, such as groundwater basin recharge, water markets, source protection, and most large infrastructure projects.

Progress in Decentralized Portfolio Management

In recent decades, many local and regional urban water agencies have moved toward more diversified portfolio approaches, with greater emphasis on tools that stretch available water supplies to complement existing surface and groundwater sources. Thus, pricing, subsidies, public education, and landscape watering ordinances have been used to encourage urban demand reductions, and investments have been undertaken to augment usable supplies by desalting brackish groundwater, treating recycled wastewater, reducing operational losses, building interties (or interconnections between water distribution systems) to allow utilities to manage their supplies jointly, and recharging groundwater basins with surface water and captured stormwater. In the agricultural sector, water use efficiency techniques have become widespread in areas facing chronic shortages. In addition, as described further below, an active water market has developed within the state, enabling temporary and longer-term reallocation of water from lower-value (mainly agricultural) activities to higher-value activities in farming and urban sectors and to the environment. This market has been combined, in some areas, with active groundwater recharge (or "banking") to balance supplies across wetter and drier years (Box 6.1).

The state has promoted these shifts through legal reforms (e.g., to facilitate water marketing, to require low-flow plumbing fixtures), direct intervention (e.g., as a broker in the water market), and subsidies for some nontraditional

6.1**Effective portfolios: the whole exceeds the sum of its parts**

In addition to providing benefits from diversification, portfolio tools can often work together to increase the overall effectiveness of individual tools, as the following examples illustrate:

Proceeds from water marketing were used to support investments in agricultural water conservation in the Imperial Irrigation District (Gray 1994a) and to support flood management investments in Yuba County (Water Education Foundation 2007).

Reservoir reoperation—allowing greater releases of dry-year storage—has been used to increase groundwater infiltration and storage in the Friant-Kern Canal service area (Vaux 1986).

Urban water conservation has increased water storage in the East Bay Municipal Utility District’s reservoirs and Southern Californian aquifers.

Water markets have provided incentives for changes in operation and groundwater banking in Kern County and Southern California (Pulido-Velázquez, Jenkins, and Lund 2004; Harou and Lund 2008).

Recycled water has augmented water supply reliability and reduced discharge of treated wastewater to the environment in Orange County (www.gwrsystem.com).

activities (e.g., water use efficiency investments and recycled wastewater plants). Often, these subsidies have sought to encourage collaboration among local agencies, most notably through the Integrated Regional Water Management (IRWM) program, which has allocated more than \$2 billion in general obligation bond funds to these efforts since 2000.²

Efforts to diversify water supply portfolios and increase coordination have helped improve California’s ability to cope with scarcity (Chapter 2). Nevertheless, major technical and institutional challenges remain to integrate these wide-ranging options into a coherent set of activities at local, regional, and state levels.

Technical Gaps in Portfolio Analysis

Determining how to combine options cost-effectively requires sophisticated analytical support and computer modeling.³ Some local and regional agencies already

2. Proposition 13 (March 2000) provided \$235 million in local assistance grants to the Santa Ana Watershed Project Authority. Proposition 50 (November 2002) set aside \$500 million to fund competitive grants for projects consistent with an adopted IRWM plan. Proposition 84 (November 2006) provided \$1 billion for IRWM planning and implementation. Proposition 1E (November 2006) provided \$300 million for IRWM stormwater flood management.

3. See Jenkins and Lund (2000) and Lund and Israel (1995a) for some examples from the research literature.

employ decision support tools to develop their portfolios. The Metropolitan Water District of Southern California, for example, uses a set of simulation models to develop a wide-ranging portfolio of water sources, storage facilities, water conservation activities, as well as wastewater reuse, water marketing, and other options suitable for meeting regional demands over a wide range of wet and dry years (Metropolitan Water District of Southern California 2010). The San Diego County Water Authority has employed optimization modeling to identify and integrate a similarly wide range of water management actions (San Diego County Water Authority 1997). However, in many cases, investment choices are being made without the benefit of integrated decision support.

The technical gap may be most pronounced at the level of statewide planning. Although the last two issues of the *California Water Plan Update* (Bulletins 160-05 and 160-09) have emphasized integrated portfolio approaches to water system planning, neither exercise used portfolio modeling tools to quantify effective combinations of options. Instead, the plans discuss potential water supply benefits of a range of options one-by-one, often without quantitative estimates of supply potential or costs. The plans acknowledge the complementarities among some options but make no attempt to quantify how they might interact and the relative roles each might have in cost-effective regional and statewide water management under different future scenarios.⁴

The lack of integrated decision support will not stop innovation in water supply management, but it can lead to misjudgment of the actual savings potential from some options and a failure to recognize the benefits of others. It also deprives policy discussions of promising integrated alternatives for consideration and can muddle these discussions with unnecessary technical controversies.

Modeling Insights

To illustrate the value of integrating water supply management options statewide, we provide some results from the CALVIN model (Jenkins et al. 2004; Pulido-Velázquez, Jenkins, and Lund 2004). Computer models of water systems are commonly used in water management because they can explicitly represent what is known about complex systems, thereby providing a platform for

4. See, for instance, the discussion of resource management strategies in Bulletin 160-09 (pp. 18–19 of the executive summary and Volume 2; California Department of Water Resources 2009). DWR does use its Least-Cost Planning Simulation model to examine promising portfolios of water management activities within the Southern California and San Francisco Bay metropolitan areas (Hoagland 2010), but it does not currently have capabilities to do this type of analysis for the state.

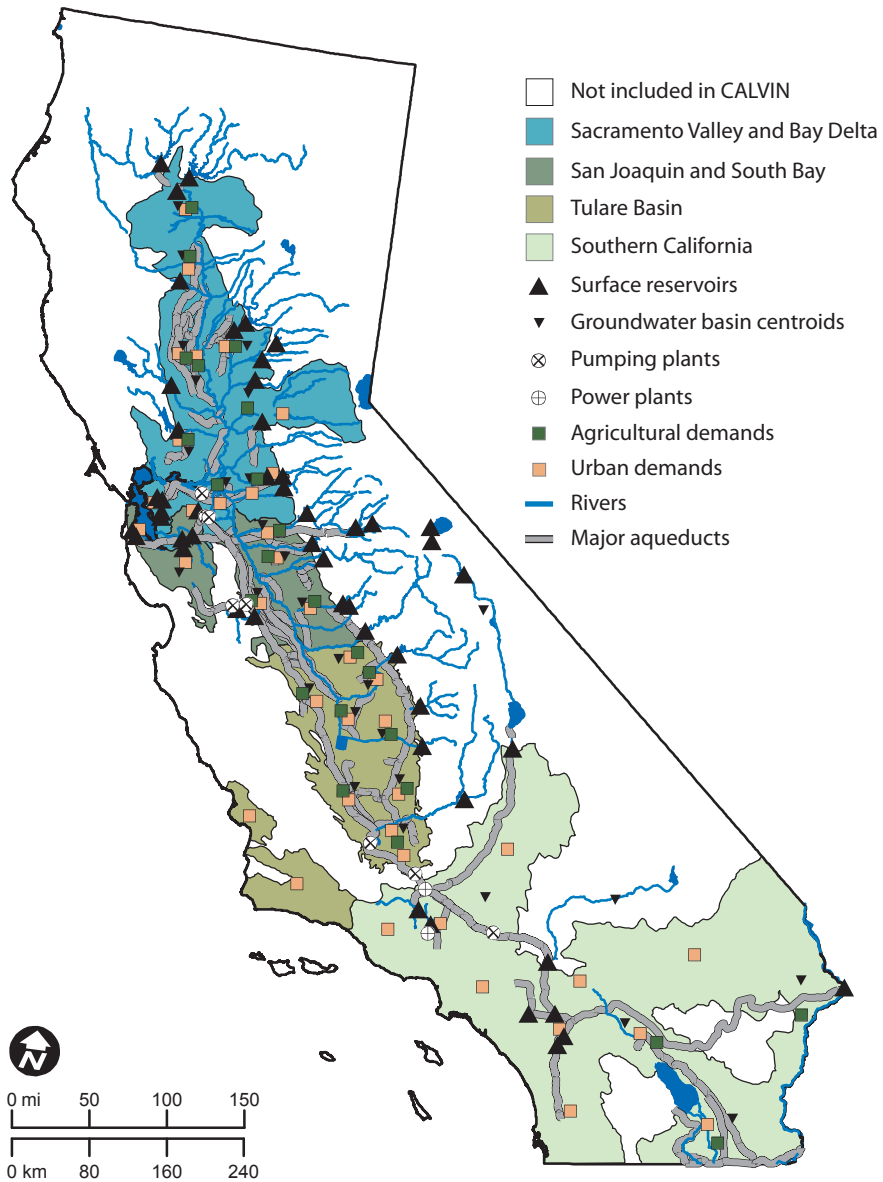
exploring problems and solutions. This computer model combines economic and engineering representations of most major elements of California's water supply system, identified by asterisks in Table 6.1, such as water markets, pricing, reoperation and coordination of reservoir and aquifer operations, water conservation, water recycling, and desalination. CALVIN seeks least-cost ways to serve urban and agricultural water demands throughout most of the state while meeting environmental flow requirements (see Figure 6.1 for geographic and system coverage).

This model has provided insights into how California's water system can adapt to a wide variety of strategic opportunities and challenges (Jenkins et al. 2004; Pulido-Velázquez, Jenkins, and Lund 2004; Null and Lund 2006; Tanaka et al. 2006, in press; Medellín-Azuara et al. 2008b; Harou et al. 2010). In general, CALVIN has highlighted the value of tools that enhance the flexibility of the water system and make the most of existing system assets. Accurate price signals and a well-functioning water market are important for encouraging demand reduction and reallocation of water from lower- to higher-value uses. Integrated system operation—which treats all major groundwater basins, surface storage reservoirs, and conveyance facilities as part of a larger network—facilitates water marketing and makes it possible to better exploit the potential for conjunctive use of groundwater and surface water and the wide range of integrated options. In this integrated system, conveyance is generally the most valuable system asset, in the sense that it is far more valuable to expand or enhance some interconnections, to facilitate conjunctive use and marketing, than to build new surface reservoirs.

All modeling has limitations. The CALVIN model idealizes water management in three important ways. First, it generally assumes that managers do not face institutional barriers to implementing the most cost-effective decisions. As a result, it can understate the costs of some adaptations (for example, if cumbersome administrative procedures or local political pressure in the source region prevents the use of water transfers, leading to greater shortages in other regions) (Tanaka et al. in press). Second, it assumes that managers have perfect foresight of hydrologic conditions. As a result, it somewhat understates some of the higher cost elements of a water supply portfolio as hedges against risk and overstates the benefits of reoperations, particularly for flood management (Draper 2001). Third, by representing water recycling and seawater desalination with average costs per acre-foot, when their initial investment costs are in fact large and irreversible, the model often understates the costs of using these options.

Figure 6.1

The CALVIN model includes most of California's water supply system and water demands



Effects of climate change, cutbacks in Delta exports, and urban conservation

The model gives insights into water management possibilities for a variety of future scenarios, including changes in hydrology, demands, technology, system assets, and policies and regulations. Here, we explore the implications of two major management challenges that California may well face by the mid-21st century: (1) significant restrictions in water supply from the system's hub in the Sacramento–San Joaquin Delta and (2) drier overall conditions resulting from climate change. In looking at adaptation options, we consider how a major behavioral and technological shift—a major successful urban water conservation effort—could help California cope with these challenges. We look at urban, rather than agricultural, conservation as an explicit policy tool, because most agricultural water use efficiency efforts do not result in net water savings without extensive fallowing (Box 2.1; Chapter 3). The model does project large reductions in net agricultural water use from fallowing under some conditions, as this is a relatively cost-effective way to respond to shortages.

To examine these changes, we compare a base case with historical conditions for climate, Delta exports, and urban water use with scenarios where urban water use is cut by 30 percent and Delta exports are restricted (Table 6.3).⁵ The reductions in Delta exports reflect increasing restrictions on pumping operations arising from native species declines as well as physical collapse of the system from widespread levee failure (Lund et al. 2010). Two climate scenarios are considered: historical climate conditions and a warm-dry type of climate, as employed in the state's most recent biennial assessment of the potential effects of climate change (Adams et al. 2010). As noted in Chapter 3, although most studies agree that temperatures in California will rise, there is no consensus on whether California's climate will be drier or wetter. This drier scenario provides a moderately extreme climate test of the state's water system.⁶

One important, and somewhat unrealistic, assumption is that this leap in urban water conservation is achieved for free. In reality, such conservation would incur significant up-front costs, at least in a transition period where

5. More complete results appear in Ragatz 2011. Previous CALVIN results have looked separately at the effects of climate change (Tanaka et al. in press; Medellin-Azuara et al. 2008b; Harou et al. 2010) and cutbacks in Delta exports (Lund et al. 2010, Tanaka et al. in press).

6. Other studies have shown that the reduction in stream flow in this climate change scenario is more problematic for water management than the increase in temperature, because existing surface reservoirs are able to absorb much of the additional early runoff associated with reduced snowpack and earlier snowmelt (Connell 2009). Given California's fairly large reservoir capacity, wetter climates tend to have much lower water supply costs but could easily have much greater flood management costs (Tanaka et al. 2006; Zhu et al. 2007).

Table 6.3
Assumptions for 2050 water management scenarios

Scenarios	Climate	Urban water use (gpcd) ^a	Delta exports range	Costs per acre-foot of new supply technologies (2008 \$)
Base case	Historical climate	2000 levels (221)	Full exports only (pre-2007 operating rules)	Desalination: 2,072 Recycled wastewater: 1,480
Policy changes with historical climate	Historical climate	30% reduction (154)	Full to zero exports	Desalination: 1,628 Recycled wastewater: 1,480 for new plants 518 for existing plants
Policy changes with warm-dry climate	+8.1°F and -26% stream flow	30% reduction (154)	Full to zero exports	Desalination: 1,628 Recycled wastewater: 1,480 for new plants 518 for existing plants

SOURCE: Ragatz (2011).

NOTES: The model assumes 2050 land use and population from Landis and Reilly 2002, with 65 million residents. Urban water use includes conveyance losses. The 30 percent reduction applies to residential and commercial uses but not to industrial uses, and the cuts are split proportionately between indoor and outdoor uses. The historical climate assumes conditions from 1922 to 1993. For other assumptions, see Ragatz (2011).

^aGallons per capita per day.

existing water users change plumbing, appliances, and landscaping to lower water-using technologies and plants (Table 6.2; Hanak and Davis 2006). However, by allowing energy as well as water savings, many indoor conservation measures can actually save costs over the longer run.⁷ Following a transition period, the assumption of no additional costs would be consistent with a shift in behaviors and tastes such that the new norms do not constitute a great overall hardship. Other advanced economies with semiarid climates, such as Spain, Australia, and Israel, where per capita urban water use is much lower, provide some models for California in this regard (Chapter 3).

Key findings

This modeling exercise yields important insights about the potential roles of conservation, infrastructure investments, and new water supply technologies in California's future. Perhaps the most striking finding is the potential role of urban conservation in managing climate change and reductions in Delta exports.

7. See Cooley et al. (2010) for some examples, including low-flow showerhead replacement, more efficient front-loading clothes washers, faucet aerators, and a variety of commercial appliances.

1. **Urban conservation can significantly reduce pressure for Delta exports.** With a historical climate, the demand for Delta exports would drop from 5.7 million acre-feet (maf) (the base case), to 3.9 maf in response to 30 percent urban conservation. The savings are reduced with a warmer and drier climate: the base case demand for Delta exports is higher (6 maf, essentially full pre-2007 capacity), and conservation reduces export demands only to 5.4 maf.
2. **Urban conservation can free up some supplies for agricultural uses.** This effect is particularly pronounced under a drier climate (Figure 6.2). Given the high economic value of urban water use, which would likely increase following 30 percent urban water conservation, climate change and reductions in Delta exports have little, if any, effect on urban water deliveries. Almost all additional shortages from climate change and reductions in Delta exports are borne by agricultural water users, many of whom would still have incentives to sell water to urban users.
3. **Urban conservation can significantly reduce operating costs and generate energy savings.** Conservation reduces pumping for long-distance imports of water to Southern California from the Delta and the Colorado River (Figure 6.3).⁸ Reductions in Delta water exports capacity further decrease water operation costs, mostly because less water is available to pump and treat. However, a drier climate increases use and costs for water reuse and seawater desalination. Although these results doubtless understate the initial costs to the urban sector of achieving conservation, the operational savings from conservation are likely to be durable.
4. **A warmer, drier climate raises the costs of Delta pumping cutbacks substantially.** Drier conditions raise the costs of shortages by at least \$1 billion per year for each scenario (to see this, compare each pairwise orange and green bar in Figure 6.3). With a warmer, drier climate, the added costs of a complete

8. With full exports, this conservation scenario reduces state and federal project energy use by 40 percent; if Delta exports are ended altogether, energy use goes down by more than two-thirds (Bates 2010a).

shutdown of the pumps more than doubles, jumping to \$2.8 billion/year, more than wiping out the cost savings from the urban water conservation program (compare the orange bars in the base case and the no export scenarios in Figure 6.3). Increases in water shortages occur primarily in the agricultural sector, as water-short urban users purchase water from farmers with more secure rights (Figure 6.4). The costs to the statewide economy would be even higher if these transfers were blocked.⁹ These results highlight the value of building alternative conveyance—either a peripheral canal around the Delta or a tunnel underneath the Delta—to allow continued movement of water to urban and agricultural water users.

5. **Delta pumping cutbacks and a drier climate reduce the value of new surface storage.** Delta cutbacks, on their own, substantially reduce the value of expanding Northern California surface storage, because it becomes increasingly difficult (and ultimately impossible) to move water to water users south and west of the Delta. A warm-dry climate, on its own, has a similar and more widespread effect, because most reservoirs rarely fill.¹⁰ Even with a warmer-wetter climate, with more precipitation and earlier runoff, expanding conjunctive use and groundwater banking appears more cost-effective than expanding surface storage (Tanaka et al. 2006). Conjunctive use projects south of the Delta also become more difficult with Delta pumping cutbacks and with a warm-dry form of climate change, as it is harder to obtain water for aquifer recharge. Delta pumping cutbacks also raise the value of new conveyance interties in regions south and west of the Delta, to better employ available supplies.
6. **Delta pumping cutbacks and a drier climate make recycled water and desalination more valuable.** The 30 percent reduction in urban water demand, by itself, would lead water agencies to dramatically reduce new investments in these

9. In a scenario using historical hydrology and base case demands, the loss of the ability to transfer water with a Delta shutdown increased costs by \$700 million/year, or 47 percent (Lund et al. 2010; Tanaka et al. in press).

10. For results with Delta cutbacks on their own, see Ragatz (2011) and Tanaka et al. (in press). For a warm-dry climate on its own, see Ragatz (2011); Tanaka et al. (2006); Medellin-Azuara et al. (2008b); and Harou et al. (2010).

more expensive water sources (Figure 6.4), although use of most existing water recycling plants would likely continue.¹¹ A drier, warmer climate plus an end of Delta exports encourage a significant increase in water reuse and desalination statewide, even with 30 percent urban water conservation. Nevertheless, water recycling and desalination remain a small proportion of statewide water supplies.

In sum, these results suggest that a major effort in urban water conservation—along the lines now being sought under legislation passed in 2009—can lessen the brunt of Delta export cutbacks and the costs to the economy from a warmer, drier climate.¹² However, even with substantial additional urban water conservation, a drier, warmer climate makes continued Delta water exports much more valuable, highlighting the value of new conveyance infrastructure to permit these exports to continue. Decisions about other major infrastructure investments also depend on these outcomes. In particular, it may be prudent to defer costly expansions of surface storage and focus on improving the ability of the existing system to work in an integrated manner, with the expansion of groundwater banking, select interties, and water marketing institutions.

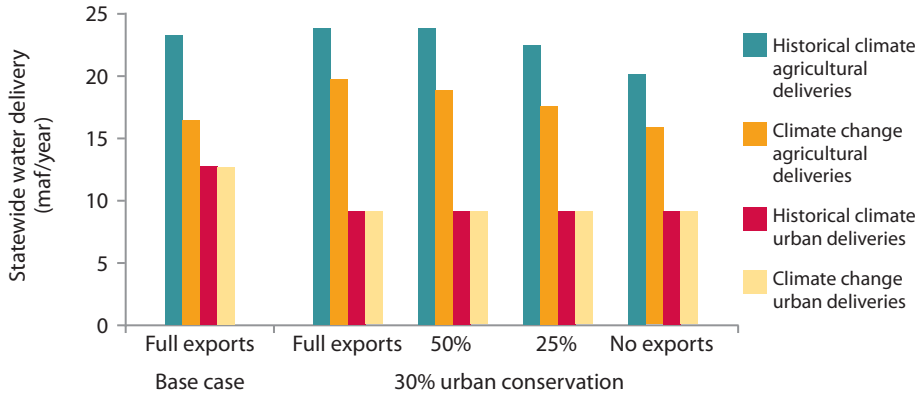
Of course, even if the state and federal governments succeed in implementing a long-term solution that allows substantial Delta exports from a peripheral canal or a tunnel under the Delta, it will take 10 to 25 years before such facilities can be completed and operational. This implies a potentially long period of diminished water supplies for Bay Area and Southern California cities and southern Central Valley agriculture, with environmental pumping restrictions and the threat of a complete shutdown of the pumps from a major earthquake. Tools to enhance flexibility—such as infrastructure and institutions to facilitate water transfers and exchanges—can help reduce agricultural and urban scarcity costs. In addition, early efforts to achieve conservation gains, along with other investments to stretch local resources (e.g., groundwater banking, stormwater capture, wastewater reuse), can help build resiliency within urban areas.

11. Although model results show decreased use of water recycling from projected current levels with 30 percent urban water conservation, the sunk costs of existing recycling plants and other wastewater disposal and water supply reliability considerations are likely to support continued use of existing water recycling plants.

12. A model run with a 40 percent reduction in urban water demand, with a warm, drier climate and no Delta exports, largely amplifies the effects of a 30 percent urban demand reduction. Total costs remain higher than for the base case of historical climate and full export capacity, but the cost savings from 40 percent conservation (assuming it is free) more than make up for the cost of lost Delta exports compared to a base case with a warm, dry climate (Ragatz 2011).

Figure 6.2

Urban water conservation would reduce agricultural water losses from reduced Delta water exports and a drier climate

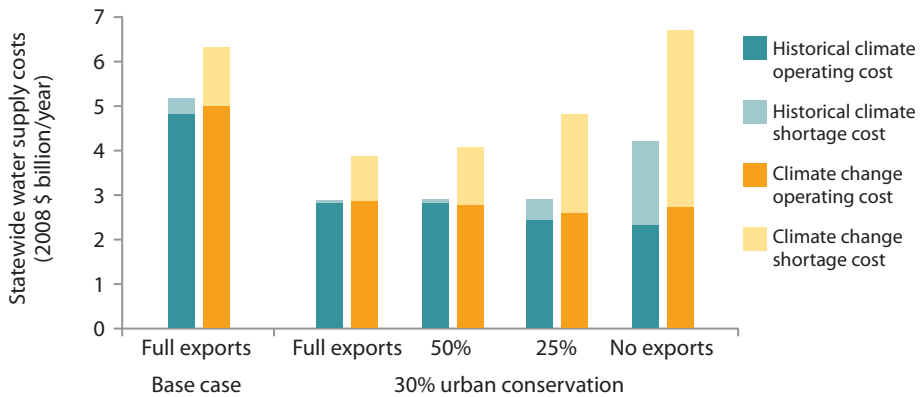


SOURCE: Ragatz (2011).

NOTES: The figure shows conditions in 2050. See Table 6.3 for scenario assumptions.

Figure 6.3

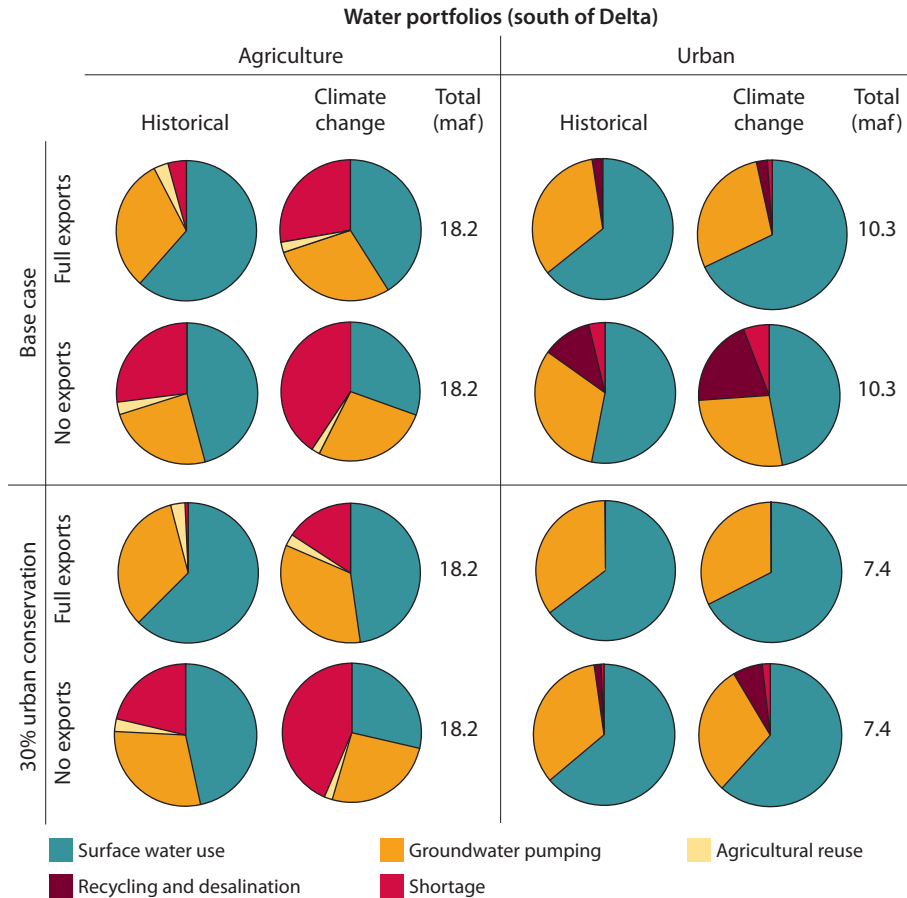
Ending Delta water exports would be particularly costly with a drier climate



SOURCE: Ragatz (2011).

NOTES: The figure shows conditions in 2050, in 2008 dollars. See Table 6.3 for scenario assumptions.

Figure 6.4
Ending Delta water exports and a drier climate would greatly reduce agricultural water deliveries south of the Delta



SOURCES: Ragatz (2011); Tanaka et al. (in press) (for base case without exports).

NOTES: The figure shows annual conditions in 2050. See Table 6.3 for scenario assumptions.

Overcoming Institutional and Legal Hurdles to Portfolio Management

The modeling results presented above highlight the importance of linking management actions together, often over great distances, as part of a portfolio approach. To strengthen water supply portfolios in the near and longer term, it will be necessary to overcome several important institutional and legal hurdles.

Here, we highlight issues in three key areas: water pricing, groundwater management, and water transfers.

Water pricing: an underutilized tool for water conservation

A variety of nonprice tools can encourage conservation: plumbing and appliance standards, landscaping ordinances and restrictions (e.g., limits on the planting of lawns and use of outdoor watering), rebates to encourage new technology adoption, and public education (Table 6.1). Water pricing should be an important part of any conservation effort, because it can reinforce the effectiveness of the many nonprice tools.¹³

Since the early 1990s drought, California's urban water agencies have made important advances in implementing conservation-oriented rate structures. In particular, many agencies have shifted from uniform to increasing block or tiered rates, which bill higher per gallon charges when water use exceeds the threshold of one or more tiers (Hanak 2005b). Another reform—the switch to volumetric billing—has begun in the many Central Valley communities that traditionally did not bill by use, as a result of federal and state laws that require a phase-in of water meters. By 2006, roughly half of California's population lived in a service area with tiered rates, and fewer than 10 percent lived in communities with unmetered rates.¹⁴ Over the past few years, there has been additional movement toward tiered rates, as urban utilities have sought to change consumer behavior in response to drought conditions and restrictions on Delta pumping. In addition, the state's large investor-owned utilities have recently adopted tiered rates as part of a California Public Utilities Commission effort to promote conservation (Box 6.2).

In broad terms, tiered rate structures provide incentives to conserve (Hewitt and Hanemann 1995; Olmstead, Hanemann, and Stavins 2007; Hanak 2008). However, there have been debates about the extent to which different rate structures can meet a variety of potentially competing objectives: economic efficiency, revenue stability, political feasibility, and ability to cover utility costs (Hall 2009). From an efficiency perspective, water users should face a price signal corresponding to the marginal cost of new supplies, which typically exceeds the average cost of existing supplies. Yet if utilities charge everyone this long-run marginal cost, they raise too much revenue (Brown and Sibley

13. We thank Michael Hanemann and Darwin Hall for discussion of many of the points raised here.

14. Authors' estimates, using rate structure information from the water rate survey by Black and Veatch (2006). These percentages are virtually unchanged from 2003 (Hanak 2005b).



In much of Southern California, integrated management of groundwater and surface water is now well established. Photo by Steven Georges/Press-Telegram/Corbis.

1986). From a political feasibility perspective, water rate structures need to be perceived as fair, which argues for transparency and simplicity. And from a revenue perspective, utilities need to be able to cover their fixed costs—typically a high component of overall costs—even if water use declines. (Structuring rates in this way is known as “decoupling,” which has been a standard feature of electricity rates in California for several decades.)

A particular type of tiered rate structure—often known in California as an “allocation-based” structure—can meet all these objectives. Allocation-based rates set tiers at different thresholds for different subgroups of ratepayers, so the volume in the base tier corresponds roughly to the amount of water an efficient household would need to use. Households using more face a higher price per gallon (corresponding to the marginal cost of water). The subgroups are defined based on readily observable factors that affect water use: household size, lot size, and climate zone, and the threshold can be adjusted across seasons to reflect the higher outdoor water requirements of plants in hotter, drier months. Utilities set the lower-tier price to recover fixed costs, and they can use additional revenues from the higher tiers to fund new supplies, including conservation programs. This system is transparent, and it sends a salient price signal to water users, because the conservation objectives embodied in the threshold are meaningful, tailored to expectations of what water users with similar characteristics should be able to do. If the prices for the tiers are allowed to vary with drought

conditions, this structure also allows utilities to meet their revenue requirement when water use declines (Hall 2009).

Allocation-based rate structures have been successful for several Southern California utilities since the early 1990s, including the City of Los Angeles and the Irvine Ranch Water District (Orange County), and in the past few years they have been adopted by several others, including the Eastern Municipal Water District and the Coachella Valley Water District (Riverside County) and the Rincon del Diablo Water District (San Diego County).¹⁵

In contrast, most tiered rate structures in California do not vary tiers by customer groups, making it harder to send salient price signals to most water users (thereby generating an efficiency loss). In addition, with calls to restrict water use in the recent drought, many utilities found that they were unable to cover costs as water sales fell—evidence that they were relying on revenue from their upper tiers to cover fixed costs. The subsequent need to raise rates when customers have been reducing water use raises political problems for utilities. Such problems could be avoided if utilities had the flexibility to implement a drought rate structure, whereby prices in the tiers are adjusted in advance to drought conditions (as Los Angeles does; Hall 2009). With an allocation-based structure, tiers also can be adjusted over time to encourage progressive conservation. For instance, Irvine Ranch recently reduced its base allocation to encourage higher outdoor water use efficiency. Effective communication with the public is an important part of such programs. This includes not only information on why unit prices may need to rise when water use declines but also information on which conservation actions can most effectively reduce water use. A recent survey for the Association of California Water Agencies found that a strong majority of the state's residents support the idea of reducing household water use (Fairbank, Maslin, Maullin, Metz & Associates 2010). But this same survey found that most homeowners underestimated the dominant role of landscape irrigation in total water use.

As California moves to implement an aggressive urban water conservation program, more utilities should consider using allocation-based rate structures. Opponents of this approach often voice concerns over the costs of implementation, given higher data needs. But advances in information technology have brought down the data costs of establishing allocations for different lot sizes:

15. Some of these utilities use more than two tiers; Hall (2009) and Michael Hanemann (personal communication) argue that a simpler system, with just two tiers, is preferable.

Digitized parcel maps are readily available for most counties, as are climate maps that reflect outdoor watering needs. And customers can have the option to declare household size. Another objection sometimes raised is that it is “unfair” to give larger base allocations to residents with larger lots (many of whom have higher incomes). Allocation-based rate structures are not “fair” in the sense of treating everyone exactly the same. But they end up being fair in a broader sense, because each group of customers ends up paying about the same average price per unit of water. By grouping customers more homogeneously by factors such as lot size and location, it is possible to send a meaningful price signal to all water users, to encourage efficient water use.¹⁶

Recent experience with investor-owned utilities (Box 6.2) also suggests that the state could benefit from conducting periodic rate reviews of publicly owned water utilities from the standpoint of conservation objectives (Chapter 8). Such reviews could provide an impartial technical analysis, helping to depoliticize rate-setting and helping utilities to maintain a solid financial footing while encouraging water use reductions.

6.2

Conservation-oriented rate reform by investor-owned utilities

Privately owned water utilities serve roughly one-fifth of California’s households. In contrast to public sector water suppliers, private utilities have rate structures regulated by the California Public Utilities Commission (CPUC). Because they are less constrained by local politics, however, private utilities often can make policy changes more rapidly. Past rate-setting rules adopted by the CPUC restricted private utilities from adopting conservation-oriented rate structures. In 2006, roughly half of the state’s population lived in areas with tiered water rates, but no private water utility had this type of rate structure. Following a policy change that year at the CPUC, accompanied by legislation requiring that private utilities review rates within a short time frame, all 10 major private utilities will have adopted tiered rate structures by the end of 2010. This rate reform includes careful attention to the principle of “decoupling,” long used in the energy sector, so that utilities can cover their fixed costs even if water use falls considerably. Lack of decoupling has been problematic for many public sector utilities implementing tiered rates.

16. Utilities can establish lifeline rates to subsidize low-income households who cannot afford full water rates (something already done in some areas). To address equity concerns, utilities can also look to their policies regarding fixed service fees. Utilities that cover a portion of their fixed costs with a fixed fee usually charge higher fees for larger meters, which require a higher level of service (higher water pressure). For the smallest meters (3/4 in.), utilities could also waive the meter fee and rely entirely on commodity charges. With lower fixed charges, the higher tier will typically need to be higher.

Filling the gaps in groundwater management

Increased integration of surface water and groundwater is essential for portfolio management of California's water resources. Water banks use available space in aquifers to store imported surface water both to recharge the aquifer and for subsequent pumping for local and export uses.

Blending imported surface water with local groundwater recharge raises a variety of difficult administrative and accounting questions, however. As a group, landowners overlying the basin have superior rights to pump the local (or "native") groundwater up to the so-called "safe yield" of the basin relative to any other users. Importers, meanwhile, have exclusive rights to the surface water they import and store in the basin (*Los Angeles v. San Fernando* 1975; Kletzing 1988). To implement a groundwater banking project, it is necessary to have an effective means of measuring inflows (both imports and local recharge) and outflows (including pumping for local uses and for export). It is also necessary to anticipate possible effects of the project on local storage availability. Sometimes, importing water benefits local users by raising the level of the groundwater table, which reduces pumping costs. But in other cases, imported water may harm local users by displacing storage capacity in the aquifer that would have captured local recharge, to which they have superior rights. Water quality also may be an issue if imported supplies contain higher levels of salts than the local water or if recharge from overlying surface sources contains pollutants that would contaminate water recharged from other sources.

The creation of water banks has been hampered by several lingering legal uncertainties. These include the archaic separation of surface water rights and groundwater rights systems, as well as questions about local landowners' rights to exclude others from using the aquifer space beneath their lands for storage of imported water.

These problems have largely been overcome in Southern California's adjudicated groundwater basins, where monitoring and accounting systems exist and there is clarity on who has rights to withdraw water from the aquifer (Figure 4.1). Banking is also relatively straightforward in the state's few special groundwater management districts, where a single agency is responsible for managing recharge and has authority to charge pump fees to cover the costs. In some other areas—notably Kern County—active groundwater banking systems have been established based on looser arrangements, which include careful monitoring and an agreement with neighboring groundwater pumpers that withdrawals from the bank will not harm local parties (Thomas 2001; Hanak 2003). Such schemes can

work if local pumpers outside the scheme cannot cause significant drawdown of the aquifer, jeopardizing the stocks of banked water funded by others. But generally, more comprehensive basin management mechanisms are needed to increase conjunctive use operations in the state, an issue we return to in Chapter 7.

A related problem arising from the disjunction of surface and groundwater rights systems is the inability of water managers and state regulators to protect surface water resources from being undermined by groundwater pumping. This has been a problem in a variety of watersheds around the state, including the Shasta, Cosumnes, Russian, and Santa Clara stream systems, where combined surface and groundwater extractions have lowered stream flows to the detriment of water quality, fisheries, and consumptive users alike (Hall, 2010; Howard and Merrifield 2010). As described in Chapter 7, in the absence of legislative response to these problems, the reasonable use mandate of Article X, § 2, of the California constitution and the public trust doctrine may be employed to bridge this historical divide between the surface and groundwater rights systems.

Water marketing: getting past the growing pains of adolescence

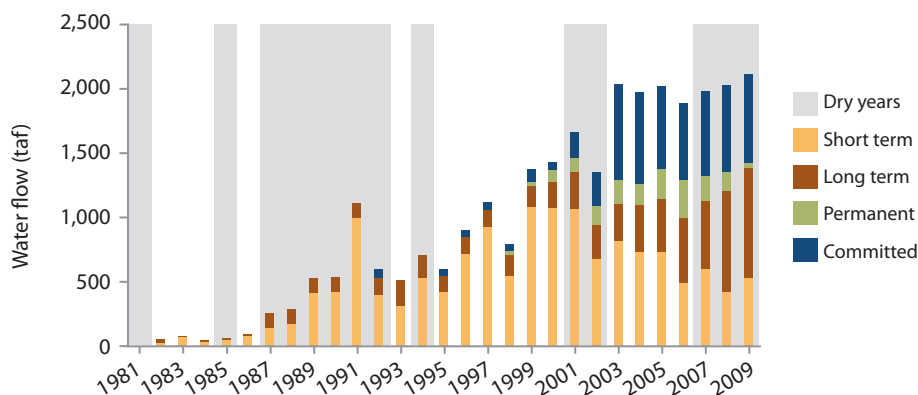
State and federal legislation passed in the 1980s and early 1990s paved the way for California's water market. New state laws clarified that transferring water is a beneficial use (to lessen sellers' fears that they might lose the rights to use water in subsequent years), extended "no injury" protections against negative "third party" impacts on fish and wildlife (to ease concerns of environmental managers and stakeholders that water movements would negatively affect the quantity and quality of environmental flows), and required that owners of conveyance facilities lease space for transferred water if they had excess capacity (Table 2.7). The federal Central Valley Project Improvement Act of 1992 also encouraged water marketing.

These legal changes, along with active participation in the market by both state and federal agencies, helped jumpstart an active water market in the early 1990s, when California was in the midst of a major drought (Israel and Lund 1995; Gray 1996; Haddad 2000; Hanak 2003). The market continued to grow when the rains returned, and by the early 2000s, the annual volume of water committed for sale or lease was on the order of 2 million acre-feet, with roughly 1.5 million acre-feet moving between parties in any given year (Figure 6.5).¹⁷

17. Figure 6.5 reports transactions between water districts. In addition, many water districts have established active water markets within their own jurisdictions, so that local users can trade among themselves as water demands and supplies change (Archibald et al. 1992; Thompson 1993; Carey, Sunding, and Zilberman 2001).

Figure 6.5

California's water market grew in the 1990s but has flattened since the early 2000s



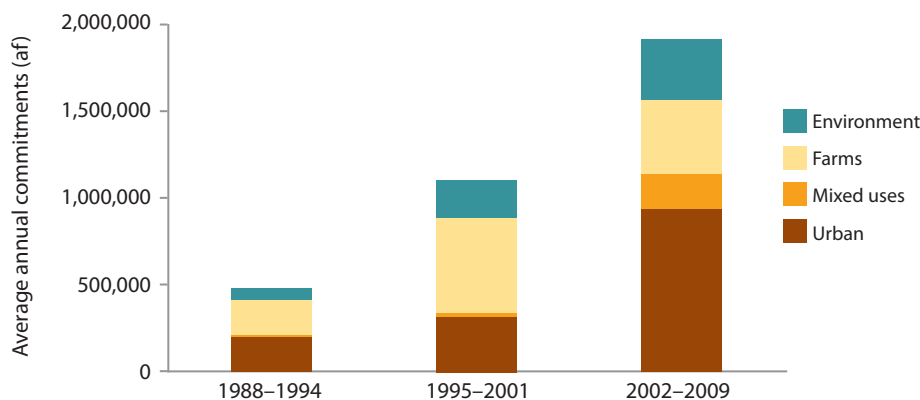
SOURCE: Hanak (2003) for 1981–2001; authors' updates from various sources for 2002–2009.

NOTES: The figure shows actual flows under short- and long-term lease contracts, estimated flows under permanent sale contracts, and the additional volumes committed under long-term and permanent contracts that were not transferred in those years. The database includes transactions between water districts, federal and state agencies, and private parties that are not members of the same water district or wholesale agency (for a description of methods, see Appendix A in Hanak 2003).

Consistent with the relative share of agricultural water use in the state's overall supply, farmers have always been the primary sellers in California's water market. But over time, there have been shifts in the nature of contracts and the uses of purchased water. During the 1990s, the market consisted primarily of short-term (single-year) transfers, with long-term contracts constituting only about 20 percent of total volumes. By the end of the 2000s, long-term and permanent sales accounted for most of the volume traded. Along with this transition, farmers have declined in importance as buyers, constituting only 22 percent of all contractual commitments in the 2002–2009 period and only 34 percent of actual flows (Figure 6.6). Water purchases for environmental flows and wildlife refuges have remained important in this decade (one-fifth of all commitments and one-quarter of all flows), but the major increases have been by urban agencies, which now account for nearly half of all commitments (more if one includes agencies with mixed water uses) and 37 percent of flows. Long-term contracts among water districts that use Colorado River water have accounted for a substantial share of this growth: With the conclusion of the Quantification Settlement Agreement (QSA) in 2003, over 600,000 acre-feet

Figure 6.6

Urban water purchases now account for at least half of the market



SOURCES: Hanak (2003) for 1988–2001; authors' updates from various sources for 2002–2009.

NOTES: The figure shows shares of all committed transfers (short-term flows and contract volumes for long-term and permanent sales). Mixed uses denote purchase by agencies with both urban and agricultural uses, such as the Coachella Valley Water District and the San Luis Delta Mendota Water Authority.

of farm water transfers are now committed, mostly to urban users.¹⁸ Urban agencies within the Central Valley have also made local purchases from agricultural agencies, and some Southern California urban agencies have successfully purchased agricultural contract water from SWP contractors in the San Joaquin Valley. These long-term transfers have been made possible through a combination of system efficiency improvements (e.g., canal lining and operational improvements), agricultural land retirement, on-farm irrigation efficiency improvements (where improved efficiency generates net water savings, such as Imperial Irrigation District), and releases of water from surface and groundwater reservoirs (e.g., from Yuba County).

The growth of long-term and permanent transfers—which generally involve more complex negotiations and more in-depth environmental documentation—is a sign that the market is maturing. Long-term commitments are

18. See Chapter 2. The new transfer agreements from the early 2000s include the movement of 303,000 af/year of water from the Imperial Irrigation District (IID) to the San Diego County Water Authority and the Coachella Valley Water District, two canal lining projects that will move nearly 96,000 af/year of conserved water from IID and Coachella to San Diego and the San Luis Rey Indians, and the movement of up to 111,000 af/year from the Palo Verde Irrigation District (PVID) to the Metropolitan Water District of Southern California. The QSA also recognizes an existing transfer of 110,000 af/year from IID and Metropolitan, in place since the late 1980s. In addition to these long-term agreements, some temporary transfers have taken place between PVID and Metropolitan during the recent drought.

particularly important for supporting economic transitions. By law, urban water agencies need to demonstrate long-term supplies to support new development, and transfers can provide this assurance. Long-term commitments for environmental flows provide flexibility for environmental managers and reduce the conflicts associated with regulatory alternatives to market-based transactions. Long-term commitments to make temporary supplies available—such as the recent 25-year transfer agreement between the Yuba County Water Agency and the Department of Water Resources—enhance operational flexibility. (In this transfer agreement, supplies are made available annually to a pool of State Water Project (SWP) and Central Valley Project (CVP) contractors, who can bid on available volumes.)

Despite these positive market developments, there is also evidence of overall weakening in market momentum. Overall trading volumes have leveled off since the early 2000s; excluding Colorado River transactions, both committed and actual flows have declined since 2001. This trend is particularly worrisome because drought conditions in the last few years should have boosted sales.

A variety of impediments—some long-standing and some new—appear to be at work (Hanak in press). One new problem relates to conveyance infrastructure. Water markets require an ability to move water from sellers to buyers (Israel and Lund 1995). California's sophisticated supply infrastructure has made it possible to transfer water either directly or through exchanges throughout most of the state's demand and supply areas (Figures 2.6, 6.1). However, the Delta is an important conveyance hub for north-to-south and east-to-west transfers, and new pumping restrictions since late 2007 have impeded both movements.

Other obstacles reflect legal and institutional impediments. Because California does not regulate groundwater at the state level, the no injury protections for other legal surface water users (including fish and wildlife) do not extend to groundwater users. This omission has spurred the development of county ordinances restricting water exports in many rural counties that lack more comprehensive forms of groundwater management (Hanak and Dyckman 2003). Local groundwater ordinances have restricted direct sales of groundwater as well as transfers based on conjunctive use (selling surface water and pumping groundwater), and they have also restricted the development of groundwater banks in some places (Hanak 2003, 2005a). Although these ordinances were a useful stop-gap measure to prevent harm to local users, they are less efficient than comprehensive basin management schemes, which address locally generated overdraft as well as problems related to exports.

Another local concern in source regions has been the potential effects on the local economy of fallowing or land retirement. These “pecuniary” effects are not proscribed under state law, which generally views such changes as a natural consequence of shifts in the economy—much as a new freeway might affect local businesses for better or for worse.¹⁹ However, fallowing conducted for sales to the drought water banks in the early 1990s generated local concerns, and many agricultural water districts disallow fallowing-related transfers unless the water is going to other lands leased or owned by the same farmer. Because fallowing of low-value crops is one of the most efficient and effective ways to make new net water available for other uses, continued local resistance will remain an obstacle to market development. In two long-term transfers of Colorado River water that involve fallowing (from Palo Verde Irrigation District and Imperial Irrigation District), buyers have supplied mitigation funds to address community effects. Agreement on the size of the mitigation fund was particularly contentious for the transfer from Imperial, and the community has had difficulties determining how mitigation funds should be spent.²⁰ Developing templates for such mitigation payments will be important for managing economic transitions (Chapter 9). These programs should consider not only residents who may become unemployed as a result of fallowing but also the potential increase in social service costs and reduction in tax revenues for counties in the region where fallowing is occurring.

Another market obstacle relates to environmental protections. Over time, transfers have been subjected to additional environmental restrictions, beyond the requirement of no injury to environmental flow conditions. For instance, under the 2009 drought water bank program operated by DWR, fallowing of rice fields was restricted to protect the habitat of the giant garter snake, a listed species that now depends on artificial wetlands created by irrigation water. Use of diesel pumps for groundwater-substitution transfers was also restricted because it was deemed to violate Clean Air Act rules, which farmers are normally exempt from when they operate pumps for their own activities.

19. State law does require public hearings on transfers that will exceed 20 percent of local water use, however (§ 1745.05).

20. In 2007, IID and the San Diego County Water Authority came to an agreement that roughly doubled and capped the amount paid by San Diego for socioeconomic mitigation at \$40 million and that increased the price San Diego would pay IID for the water (Imperial Irrigation District and San Diego County Water Authority 2007). Under the agreement, IID also will put \$10 million into the fund and is responsible for any additional socioeconomic mitigation. The community-based, volunteer local entity established to disburse funds disbursed just \$3.5 million before it was disbanded in 2008. The IID board is now serving as the local entity and has recently begun soliciting applications for mitigation funds (Lusk 2008; www.iid.com/index.aspx?page=199). In the case of the Palo Verde Irrigation District transfer to the Metropolitan Water District of Southern California, the community is just now beginning to develop guidelines for allocating the mitigation fund (initially set at \$6 million, now worth over \$7 million with accumulated interest) (W. Hasencamp, personal communication).

Uncertainties over the terms of these new restrictions, combined with the inability to move water through the Delta in the spring, depressed drought water bank activity: Fewer than 80,000 acre-feet were acquired, whereas the goal was several hundred thousand acre-feet (Hanak in press).

As discussed in Chapter 7, new mechanisms are needed to clarify and streamline environmental reviews for water transfers, particularly for medium-term agreements that create flexibility to transfer water quickly in the event of drought- or regulatory-induced shortages. Water market development also will benefit from greater integration and more uniform treatment of the various types of water rights and contracts. Current rules heavily favor transfers between agencies within the same large project (CVP, SWP, Colorado River), resulting in less efficient reallocations for short-term water management and long-term economic shifts.

The Water Quality Portfolio

California water policy discussions often focus on water supply, to the neglect of water quality. Yet there are very direct connections between the two: When water quality is impaired, it becomes less valuable as a supply source. Drinking water treatment costs increase with higher levels of contaminants, and agricultural production can be damaged by high concentrations of salts. Contaminated waters also pose threats to the environment. As described in Chapter 3, some water quality threats are growing as a result of sea level rise and rising salinity in the Delta, increasing numbers of chemicals released into the environment, and the limited effectiveness of measures to control polluted runoff from farms and urban areas.

Federal and state regulatory standards apply to the purity of potable water supplies and to the control of pollutants entering water bodies. A wide range of options are available for meeting these quality goals, falling into three broad approaches: source control (restricting the use of contaminants), pollution management (including collection, treatment, and discharge management), and pollution response (limiting the harm from spills and discharges) (Table 6.4). Water quality managers and regulators typically rely on many of these tools in combination.

Source Control

The most direct approach to reducing contaminants in water is source control, which limits or eliminates contaminants at the source. As noted in Chapter 3,

Table 6.4

Water quality management portfolio options

Source control
<ul style="list-style-type: none"> Prohibition of contaminants (e.g., DDT, polychlorinated biphenyls [PCBs]) Restricted use of contaminants (e.g., regulated pesticides such as pyrethroids) Registration and risk assessments for new chemicals (e.g., nanometals)
Pollution management
Collection and treatment
<ul style="list-style-type: none"> Collection of contaminated waters (sewerage and drainage water) Treatment of waste and drainage water Treatment wetlands (buffering effects) Natural biodegradation
Disposal
<ul style="list-style-type: none"> Dilution Discharge timing shifts Discharge elimination and reduction (water reuse) Contaminant concentration and sequestration (e.g., landfills) Discharge regulations and standards Discharge fees and price incentives Markets (cap and trade)
Pollution response
<ul style="list-style-type: none"> Treatment before use (e.g., drinking water treatment) Restricted downstream uses and warnings (e.g., fish consumption warnings, boil water advisories, beach closures) Spill response and containment Public health responses (monitoring and treatment of disease outbreaks)

tens of thousands of industrial and agricultural chemicals are already in use, and hundreds of new chemicals are registered each year. Newly developed or imported pesticides, or chemicals to be newly used as pesticides, are covered by the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). This act requires that new pesticides be registered and tested for their effects by their manufacturer and charges the Environmental Protection Agency (EPA) with setting use standards. The Toxic Substances Control Act (TSCA) gives EPA the authority to require registration, testing, and regulated use of new chemicals, except for food, drugs, cosmetics, and pesticides. It is designed to prevent very hazardous chemicals from being manufactured and sold.

Both FIFRA and TSCA seek to identify chemicals or substances that may be harmful if they enter water bodies, providing an important regulatory function for source control. However, the efficacy of these acts, and the state programs that administer them, is subject to dispute. The least effective is TSCA. Under TSCA, EPA, rather than the manufacturer, must prove that a new chemical or

substance causes harm and warrants regulation. In addition, before EPA can issue regulations, an extensive cost-benefit analysis is required to demonstrate “unreasonable risk.” For this reason, in the 45 years since its enactment, TSCA procedures have found only five chemicals that present an unreasonable risk. In addition, TSCA requires that EPA provide the public with information on chemical production and risk, but the act prohibits disclosure of confidential business information. As outlined in a critical review of TSCA by the U.S. Government Accountability Office 2009, 95 percent of notices of new chemicals provided to the EPA have some information that is claimed to be confidential. Although the standards for regulation under FIFRA and TSCA are similar, the FIFRA process is somewhat different, leading to more thorough analysis of potential harm. Under FIFRA’s licensing procedure, a great deal of testing is required by the manufacturer before a license application can be submitted. This distinction reflects the greater concerns about toxicity with pesticides, which are designed to be widely applied to kill some organisms, than with chemicals in general.

Source management of toxic contaminants is a major challenge for California as manufacturing increases in complexity (Chapter 3). One model for source reduction policy has been recently adopted by the European Union. Known as the Registration, Evaluation, Authorization and Restriction of Chemical substances program (REACH) (http://ec.europa.eu/environment/chemicals/reach/reach_intro.htm), it differs from the TSCA principally by shifting the burden of proof, and the associated costs, away from the public and to the manufacturers. Under REACH, manufacturers are required to evaluate the risks of new and existing chemicals before registering them, with different levels of testing for different quantities of chemical production.

One of California’s most successful efforts to date at regulating harmful substances has been Proposition 65, which prohibits the discharge of toxic substances that cause cancer or developmental harm into drinking water or onto lands that allow toxics to pass to drinking waters. This law also requires that businesses post warnings of listed toxic substances. The California Office of Environmental Health Hazard Assessment has listed 834 chemicals under this law (and subsequently delisted 11 of them) (oehha.ca.gov). Proposition 65, like the REACH program, shifts the burden of proof to businesses using toxic products. It relies on multiple data sources to establish a California list of toxic substances. And it provides for private enforcement, because anyone can sue to enforce Proposition 65. However, Proposition 65 is limited in its scope, because

chemicals can appear on the list only if a government (federal, state, or international) has tested it and found it to cause cancer or reproductive harm in humans.

Currently, the California Department of Toxic Substances Control is promoting a Green Chemistry Initiative that builds on some components of the REACH program and Proposition 65 (www.dtsc.ca.gov/pollutionprevention/greenchemistryinitiative/index.cfm). The program seeks to accomplish the following goals: (1) create an online product ingredient network, based on manufacturers' disclosures;²¹ (2) create a complementary online toxics clearinghouse, with known information about ecological and public health properties of chemicals made available for use in the state; and (3) encourage the development of manufacturing chemicals and processes that reduce effects on the environment. By making information on product ingredients and properties available to the public, this initiative could, like Proposition 65, create incentives for manufacturers to limit the use of harmful chemicals. This effort is in its most nascent stages but holds promise for source reduction of toxics.

Pollution Management

Most water quality management centers on controlling the amount and type of pollution that enters the state's surface and groundwater through collection, treatment, and management of discharges. For "point" sources of pollution, such as urban sewage and industrial waste, collection and treatment are generally required before disposal into water bodies. On-site retention and treatment is a growing practice for some "nonpoint" sources, such as urban stormwater. Natural buffering systems are also gaining in use. Wetlands, for example, can help filter certain contaminants from nonpoint sources of pollution and further "polish" wastewater discharge. For some contaminants, disposal can be timed to limit damage. For instance, salt discharges from agricultural areas can sometimes be held for discharge during winter storms, which dilute the concentrations of salt in the receiving waters. Similarly, some pesticides are prohibited during some seasons to help ensure that they degrade naturally before their remnants discharge into water bodies. Irrigation efficiency technologies and drainage flow management are also useful tools for reducing polluted discharges from farms.

21. Manufacturers of products sold in California would be required to tell the state what the ingredients are, and the state would disclose publicly anything considered nonproprietary.



Better source control and pollution management are priorities for policy attention. Photo by Fred Greaves/Reuters/Corbis.

Regulations governing the discharge of pollution into water bodies, under both the federal Clean Water Act and the state Porter-Cologne Act, have traditionally distinguished between point and nonpoint sources. When these laws were passed in the 1960s and 1970s, the focus was on point sources of pollution, such as factories and wastewater treatment facilities. The laws consequently emphasize regulation of point sources. This focus, along with generous federal financial support to upgrade wastewater treatment capacity in the 1970s and 1980s (covering up to 90 percent of costs), has tremendously improved the quality of water discharged from point sources (Sax et al. 2006; Salzman and Thompson 2010).

Regulators began to shift their attention toward nonpoint sources in the late 1980s and early 1990s, initially for construction activities and urban runoff in large municipalities (>100,000 persons), and since 2003 for runoff from smaller communities (>50,000).²² In California, agricultural runoff in some regions has been subject to “waivers of waste discharge,” as long as farmers engage in water quality monitoring and implement prescribed best management practices. Although the goal of addressing nonpoint sources is laudable, the efficacy of current approaches is limited. Whereas point sources are generally subject to strict numerical and technology-based standards, most nonpoint sources are

22. Because these programs involve the issuance of stormwater permits under the National Pollution Discharge Elimination System, urban runoff is legally identified as a point source, despite its nonpoint character.

required only to follow various management practices—without quantitative requirements to ensure effectiveness. In addition, the regional water quality control boards responsible for oversight generally have neither the resources nor the inclination to support rigorous enforcement programs.

Partly as a consequence, nonpoint pollution is now a primary source of water quality impairment in California. The federal Clean Water Act provided that the nation's waterways would all be fishable and swimmable by 1983 and that the nation would eliminate all discharges of pollutants by 1985. In 2004, however, 93 percent of California's river miles, 93 percent of California's lake acreage, and 98 percent of its estuarine square miles were listed as impaired (U.S. Environmental Protection Agency undated (a)). Agricultural runoff and other nonpoint sources of pollution are among the top five sources of pollution for California's rivers and streams, lakes, and estuaries (U.S. Environmental Protection Agency undated (a)). Point sources of pollution do not rank in the top five for any of these waterway types and, indeed, do not rank among the top ten sources for rivers and lakes (although they rank eighth for estuaries).

Another weakness in water quality laws is the failure to effectively integrate water quantity decisions (Hanemann and Dyckman 2009). Hydrologic modification of waterways through water diversions, dams, reservoirs, and river channelization has both degraded water quality and limited the natural ability of rivers and wetlands to restore water quality. Water supply facilities and operations are a major source of impairment in California waterways—ranking second for estuaries (behind natural sources) and third for rivers and lakes. However, federal and state water quality laws do not directly regulate most hydrologic modifications of the state's waterways.²³ Courts have split on the question of whether dams must obtain Clean Water Act permits for their discharges.²⁴

Pressured by lawsuits, federal and state regulators in the last two decades have begun to address impairment by developing quantitative limits on the discharge of specific pollutants. Such limits, known as total maximum daily

23. Indeed, in passing the federal Clean Water Act, Congress declared, as a matter of policy, that “the authority of each State to allocate quantities of water within its jurisdiction shall not be superseded, abrogated, or otherwise impaired by this Act.”

24. Dams that simply impound and release water in the same river do not need a permit, even though they alter or degrade water quality (*National Wildlife Federation v. Gorsuch* 1982). In contrast, dams that divert water from one watershed for release into another may be required to have a permit (*South Florida Water Management District v. Miccosukee Tribe of Indians* 2004; *Catskill Mountains Chapter of Trout Unlimited v. City of New York* 2001). Recent EPA regulations exempt all water transfers that move water between watersheds if the transferred water is not subjected “to intervening industrial, municipal, or commercial use” (U.S. Environmental Protection Agency undated (c)).

loads (TMDLs), can address a wide range of problems—chemicals, biohazards, sediment, trash, even temperature—alone or in combination—and can involve both point and nonpoint sources. Some TMDLs, such as temperature and sediment, also can affect water supply decisions. California’s regulators have a goal to establish over 400 TMDLs, of which over 120 are under development (State Water Resources Control Board 2010d). Lawsuits are driving the implementation schedule in several regions.²⁵

The development of TMDLs raises numerous issues. Performance-based standards are clearly needed to remediate some water quality problems, where technology standards and best management practices are falling short. However, TMDL implementation costs can be quite high, and the law does not require balancing the benefits to be gained with the costs of achieving the standards.²⁶ The question of costs and tradeoffs is particularly pertinent where targets are being set for legacy contaminants, such as mercury, where background levels meet or exceed generic standards, making it difficult, if not impossible, to comply with TMDLs. In these cases, a Use Attainability Analysis can be conducted, and if standards cannot be achieved at reasonable cost, they can be revised. In practice, however, conducting a Use Attainability Analysis is costly and time-consuming, and few are conducted. Numerous uncertainties also arise in the methods used to set TMDLs and apportion responsibility for meeting water quality standards (Box 6.3). With climate change, temperature and temperature-dependent standards will become increasingly difficult to meet.

These considerations suggest the need for greater flexibility in implementing TMDLs. One important change is to modify the procedures for conducting a Use Attainability Analysis, to make it more useful and less cumbersome. This flexibility will be especially important where regulators are operating under court-imposed deadlines to establish TMDLs, as these deadlines reduce administrative flexibility to prioritize TMDLs and informally factor in cost and feasibility considerations.

A second change, which is already encouraged by the federal Environmental Protection Agency, is to adopt and implement water quality trading programs. The idea behind pollution trading is that some dischargers may face lower costs

25. California is operating under three consent decrees covering most of the North Coast Region, all of the Los Angeles Region, and Newport Bay and its tributaries in the Santa Ana Region. Additional statewide suits are under litigation (State Water Resources Control Board 2010d).

26. Hanak and Barbour (2005) describe the debates concerning the cost of implementing a trash TMDL in Los Angeles County, which one study put at \$102 billion.

6.3**Klamath River TMDL uncertainty**

The adoption and implementation of TMDLs is a costly, politically charged exercise. To achieve water quality standards set forward by a TMDL, responsibility is apportioned among various landowner groups, water management facilities, or any other point or nonpoint sources that degrade water quality to levels below conditions necessary to support beneficial uses. In many cases, the TMDL evaluations are based on water quality modeling, with the potential for large errors that can apportion responsibilities inequitably or, worse yet, set TMDLs that can never be achieved.

The North Coast Regional Water Quality Control Board (2010a, 2010b) recently adopted a TMDL for the Klamath River in California that sets standards for temperature, nutrients, organic material, dissolved oxygen, and algal toxins. The upper half of the Klamath River (above the Shasta River) derives the bulk of its flow from upper Klamath Lake. This lake was naturally rich in nutrients (eutrophic), before land use changes, such as logging, grazing, and the draining of marshes for agriculture, augmented the nutrient load. Internal cycling of nutrients maintains the lake in a hypereutrophic state today and will do so for many generations regardless of efforts to reduce nutrient inputs (National Research Council 2004). The water that leaves the lake and flows down the Klamath River, particularly during the summer, is warm and contains high levels of nutrients and organic material and low levels of dissolved oxygen—all factors harmful to the river's salmon.

A series of reviews of the water quality model used to develop the TMDL highlighted multiple significant problems (Rounds and Sullivan 2009, 2010). Most notable is the model assumption that water quality in upper Klamath Lake will dramatically improve in the future, to a level unlikely to have occurred even in pre-European times. Continued use of this model has the potential to perpetuate conflict over water management in a basin already well known for conflict and to erode confidence in the institutions responsible for water quality regulation.

of reducing pollution than others. Most trading programs are based on a “cap and trade” principle, where the caps are the maximum pollution loads that would allow water bodies to meet their water quality standards. Within this cap, polluters are allowed to trade initial allocations in a market setting. The allocation of the total load, also required as part of the TMDL, can function as the initial allocation for a trading program. The value of a trading approach is that it promotes regional cost-effectiveness, innovation, and alignment of financial benefits with pollution reduction.

Pollution trading has been effective under the Clean Air Act to reduce sulfur dioxide emissions—largely from coal-fired electricity-generating plants (Burtraw et al. 2005). The EPA estimates that the savings from water quality trading in the United States as a whole could exceed \$900 million (U.S. Environmental Protection Agency 2004). The experience in cap and trade of nonpoint pollution in Australia suggests that market-based tools can help address salinity and a variety of other water quality issues (Young 2009).²⁷

As with other pollution trading, water quality trading raises issues that must be overcome. A prerequisite for implementing market-based instruments is a clear scientific understanding of the relationship between production practices and water pollution. This is particularly germane to nonpoint sources of pollution, where discharges cannot be directly measured. In addition, reducing discharges at one point on a waterway may not be equivalent to reducing discharges by the same amount somewhere else—requiring complex scientific evaluations of whether particular trades between distant pollution sources are appropriate. Where a particular pollutant (e.g., the discharge of toxins) has significant localized effects, moreover, trades can lead to localized health problems or “hot spots”—making these pollutants less suitable for trading. These issues notwithstanding, the potential gains from trade suggest that the careful analysis required to set up trading schemes is worth the effort.

The TMDL requirements of § 303(d) of the Clean Water Act have provided an impetus for the recent rise in pollution trading initiatives in the United States (Ribaldo 2009). Nationally, the number of trading programs increased from eight to almost 100 between 1995 and 2008. To date, most trading programs are only pilot projects, and just one, involving the Long Island Sound, has been responsible for 80 percent of the trades (Salzman and Thompson 2010). Most programs address nitrogen and phosphorus but some also include heavy metal and other pollutants (Breetz et al. 2004). Point/nonpoint trading systems for nutrients exist on 15 waterways (Ribaldo and Nickerson 2009).

Although California has been slow to embrace water quality trading, it offers the potential to help tackle numerous contaminant problems in the state cost-effectively, including salt, nitrate, nitrogen, phosphorus, and pesticide discharges. Indeed, a trading program among nonpoint source discharges has existed in the Grasslands region of the San Joaquin Valley since 1998. This program was

27. Australia is also moving in the direction of much more rigorous measurement of nonpoint sources of pollution. See Murray-Darling Basin Authority (2008).

the result of the Central Valley Regional Water Quality Control Board's 2001 promulgation of a TMDL for selenium in the lower San Joaquin River and issuance of the first waste discharge requirement for nonpoint source pollution in the United States. The cap on selenium loading has helped to meet the TMDL for most years during the program's existence, and the opportunity for trading selenium allowance among the participating dischargers has both enhanced farm operational flexibility and encouraged compliance (Breetz et al. 2004; Karkoski and Young 2000). Water pricing—with tiered rates set to encourage greater irrigation efficiency—has also been an effective component of the region's efforts to reduce selenium discharges (Wichelns, Jouston, and Cone 1997; Wichelns and Cone 2006).²⁸ The Grasslands' trading program is a model for the use of market-based trades as part of an integrated water quality regulatory strategy.

California should build on this model for managing nonpoint sources. The agricultural waiver program has established important building blocks for moving beyond monitoring and best management practices toward performance-based outcomes. Farmers are now organized in groups to conduct monitoring under the law. The next step would be to establish water quality targets these groups of farmers should collectively meet for specific contaminants in farm runoff within a well-defined area (e.g., a stretch of a river) and allow them to determine how best to meet the targets. Such an approach reduces the administrative costs of regulation and provides incentives to farmers to find least-cost approaches for complying with the standards.

Finally, for some contaminants, it may be appropriate to consider introducing surcharges on products sold, both to discourage overuse and to help fund mitigation efforts. California already does this in the case of some pollutants, such as electronic waste and old tires.

Pollution Response

The third approach to water quality is pollution response. For municipal water systems, it has long been standard practice to treat raw surface water to limit damage to human health from inadequacies or failures in upstream collection and treatment of wastes. Wellhead treatment of groundwater (which typically did not require treatment beyond chlorination) is now used in some areas where nitrates and other contaminant concentrations are too high. These actions are regulated

28. Tiered pricing is also used to limit chemical-laden urban runoff from overwatered landscapes by the Irvine Ranch Water District. Some of the proceeds from the higher-tier revenues are used to fund stormwater retention areas.

under the federal Safe Drinking Water Act and the state Porter-Cologne Act, which require that utilities meet maximum contaminant limits or cease using contaminated sources. As discussed in Chapter 3, the number of regulated contaminants in drinking water is growing and will continue to grow, raising the costs of water supply treatment and compromising some water sources for municipal uses.

A second damage reduction strategy is to restrict uses of contaminated waters. Restrictions or warnings for recreational or fishing uses downstream from contaminated discharges can help avoid harmful human contact with the contaminants, as can beach closures in the event of sewage spills and stormwater discharges. In much of California, warnings are often posted on rivers and estuaries to reduce the potential public health effects of long-term accumulation of mercury and other contaminants in the environment. Although this strategy can protect public health from contaminants that are unavoidable or too costly to contain, restricting downstream uses is obviously a less-than-ideal approach to overall contaminant management.

Finally, few viable options exist for protecting fish, other aquatic organisms, and birds and riparian species once harmful pollutants have been discharged into the state's waterways. As described in Chapter 5, contaminants are a major contributing factor in the degradation of the state's aquatic ecosystems. The growing costs of treatment for human uses and the high environmental costs of contamination both underscore the importance of strengthening upstream actions, including better source control and better pollution management, as priority areas for policy attention.

The Flood Management Portfolio

Floods are a different sort of water problem. Floods occur infrequently, arrive rapidly, dissipate quickly, and can impose significant damage and loss of life. Yet these rare, short-lived events require vigilant preparation and planning. The nature of flooding—long periods of tedious attention to detail punctuated by brief moments of frenzied terror—creates significant challenges to sustained maintenance, governance, funding, and public attention.

Options

As with water supply, many options are available for flood management (Table 6.5). Combining a range of actions can provide higher levels of flood protection at a lower overall cost to the economy and the environment (White 1945; Lund 2002; Needham et al. 2000; Woodall and Lund 2009).

Table 6.5
Flood management portfolio options

Preparatory actions
<p>Protection</p> <ul style="list-style-type: none"> Levees (peak accommodation) Flood walls and doors (peak accommodation) Closed conduits (peak accommodation) Channel improvements (peak accommodation) Reservoirs (peak reduction and duration extension) Channel bypasses (peak accommodation) Sacrificial flooding (peak reduction) Flood easements (for bypasses and areas designated for sacrificial flooding) <p>Vulnerability reduction</p> <ul style="list-style-type: none"> Relocation of vulnerable human activities Floodplain zoning and building codes Floodproofing: raising structures, sacrificial first floor, watertight doors Flood warning systems Flood insurance and reinsurance Flood risk disclosure <p>Public and policymaker education</p>
Response actions
<p>Protection</p> <ul style="list-style-type: none"> Levee and flood wall monitoring (structures and seepage) Sandbagging of levees and flood walls Flood door closure Reservoir operation <p>Vulnerability reduction</p> <ul style="list-style-type: none"> Issue warnings and evacuation calls and emergency mobilization
Recovery actions
<ul style="list-style-type: none"> Flood insurance and reinsurance Reconstruction and repair Relocation to reduce future flood vulnerability

Preparatory actions

The typical long periods between floods allow for significant preparations to both protect land from inundation and reduce vulnerability to human and economic losses when inundations occur. Traditional preparatory flood protection options include levees, dams, bypasses, and channel improvements that prevent floodwater from reaching vulnerable areas. Flood protection actions work in one of two ways: by containing the flood peak flow within a designated channel (“peak accommodation”) or by storing water to shift part of peak flows to a later time (which extends a flood’s duration at a lower flood peak). In some areas, water from smaller floods also can be spread and infiltrated into the ground to reduce downstream flood peaks and volumes. Infiltration is usually ineffective for larger floods, however, because soils tend to be saturated before they arrive.

Flood protection actions are the most traditional management activities and are often called “structural” measures. California relies heavily on levees, in addition to a major bypass system in the Sacramento Valley and numerous reservoirs (Figure 2.13) (Galloway et al. 2007; Kelley 1989). Levees are designed to accommodate flood peaks, but they weaken as they become saturated during longer-duration floods. Flood storage reservoirs reduce peaks by temporarily storing peak flows to extend flood duration. Broader bypass channels are used to accommodate larger peaks and reduce peaks somewhat. In some cases, floods can be directed to lower-value or more easily repaired areas, such as recreation fields or agricultural lands. This reduction of flood protection at one location to increase flood protection elsewhere is sometimes called “sacrificial flooding.” Flood easements are agreements with landowners to allow for the occasional flooding of areas in bypasses or areas predesignated for sacrificial flooding. The Sacramento Valley bypasses relied on one-time payments to incorporate farmland into these systems. For future expansions of such easements, compensation could also be set up as smaller annual payments to landowners and to local governments (which lose tax revenues when land cannot be developed).

Because it is impossible to prevent all floods, reducing vulnerability is also an important part of a flood management portfolio. Like seatbelts for car crashes, actions to reduce vulnerability to floods decrease damage and loss of life from inundation, rather than prevent inundation. Individuals can undertake some actions to reduce vulnerability on their own, for instance, by flood-proofing structures, purchasing flood insurance, and heeding flood evacuation warnings. However, some key management actions are regulatory in nature, in the interests of public health and safety. Floodplain zoning and building codes are important policy tools, as are mandatory insurance requirements by lenders and flood warning and evacuation systems. Vulnerability reduction is often more cost-effective than extreme levels of flood protection.

Education of the general public and policymakers also helps reduce flood risks by keeping attention on actions to protect against floods and reduce vulnerability during the often long periods between floods. An underutilized education tool is flood risk disclosure, which can encourage both insurance uptake and public willingness to support flood protection investments.²⁹

29. In preliminary work using national data, we find that the introduction of a state requirement to disclose at the time of sale that a property lies within a 100-year floodplain increased insurance uptake in these zones by nearly 15 percent.

Response actions

Flood response actions occur just before and during floods to improve or extend structural flood protection through sandbagging and enhanced inspections of levees, reservoir operations, and closure of operable flood structures. Flood warnings and evacuation can greatly reduce loss of life and damage and economic disruption from floods. Effective flood responses typically require preparatory actions and investments, such as installation of warning and evacuation systems, as well as periodic (annual) testing and exercises.

Recovery actions

Recovery tools focus on addressing disruptions from flooding. Preparation to repair damaged transportation infrastructure, businesses, and homes can shorten the time to recovery and reduce the overall costs of the flood. Flood damage also sometimes presents an opportunity to reconstruct in less vulnerable ways, such as elevating structures in the floodplain or removing structures to less flood-prone locations. In some cases, it is preferable to rely on structural investments until they are destroyed by a flood, and then abandon these sunk costs or relocate the activity to a more sustainable location (Suddeth, Mount, and Lund 2010).

Disconnected Water and Land Use Management

The disconnect between water and land use management presents a major challenge for flood management. Comprehensive flood management inherently implies joint management of water and land, but this integration is often missing in practice because of institutional fragmentation. Land use decisions are primarily the prerogative of city and county governments, which have strong local economic development objectives and often rely on fees and taxes from newly developed properties for revenues. Their interests are aligned with those of the owners of undeveloped land, who stand to gain from land sales. Hence, local incentives are strong to allow urbanization of floodplains. Floodwater, meanwhile, is traditionally managed by flood control agencies at the local, state, and federal levels. Even at the local level, the county agencies responsible for flood protection typically have little authority over the land use decisions of the individual jurisdictions within their area of responsibility.

This disconnect creates perverse incentives, since the jurisdictions authorizing development are not responsible (and potentially not liable) for flood

damages. This divergence of incentives became particularly acute following the 2003 *Paterno v. State of California* decision, which found that the state was liable for all damage caused by failure of “project levees” within the state-federal flood control projects, including the large Central Valley Project (Chapter 1; for a map of project levees, see Figure 2.13). Thus, the state is now liable for damages even when locally built and maintained levees within these projects fail.

Faulty flood perceptions by residents and policymakers magnify the problems of managing land and water together for floods. Since most rivers already have some sort of flood channels, levees, and reservoirs, local residents often feel protected, even when a substantial residual risk remains that floods will overwhelm the capacity of existing infrastructure (Box 6.4).

Faulty flood risk perceptions have also restricted the availability of funding for flood management (Chapter 2). Thus, aside from the addition of flood warning systems, there has been little sustained effort to keep California’s flood infrastructure system up to date with changes in land use, updated hydrologic data, and technical advances in flood management.

Finally, flood management today and into the future is heavily influenced by land-related policy choices made over a century ago (Chapter 1). For example, the massive quantities of hydraulic mining sediment from the Sierra Nevada in the latter 19th century led flood planners to place levees close together to promote scouring of sediments and their movement downstream. These riverfront levees ended the frequent floods that supported riparian corridors and floodplain wetlands and spurred urban and agricultural development behind them. Today, these riverfront levees promote scouring (requiring more frequent maintenance), increase flood stage (as a result of confinement of flows), and, because of the development behind them, reduce the flexibility to move levees back from the river to improve flood protection and restore river and floodplain environments. In Southern California, Los Angeles’s choice in 1915 to channelize its main river allowed development up to its concrete-lined banks. Both choices—close levees to manage hydraulic mining sediment and channelization of the Los Angeles River—created a legacy that affects management today (Kelley 1989; Gumprecht 1999). The choice to crowd rivers, rather than leaving them room to adjust their shape, support habitat, and convey floods, has been repeated in all major urban areas of California (Mount 1995).

Until recently, flood management in California has been successful enough to allow sustained inattention to growing flood risks. Elected officials could almost rely on not having to worry about floods for their terms of office.

6.4

Flood risk and residual risk

Perception and calculation of flood risk are both important for managing floods. “Flood risk” is formally defined as the likelihood of flooding multiplied by the magnitude of damage (vulnerability) if flooding occurs. “Residual risk” is the flood risk that remains after management actions are taken to reduce flood frequency (protection) and flood vulnerability (damage). Because flood warning and evacuation systems are typically highly effective, such calculations usually are made only for economic losses, with potential for loss of life estimated separately.

As an example, consider the homes constructed in the Natomas area of Sacramento County. The depth of flooding likely to occur in this area approaches 22 feet, meaning that structural damage will be severe, leading to a total loss of some structures (as occurred in New Orleans). A typical home may sustain losses of \$300,000 or more as a result of deep flooding. In 2000, the system of dams and levees that protected Natomas offered only a 1-in-70-year level of protection. This translated to an approximate \$4,300 annual risk of flooding ($= \$300,000/70$), and triggered requirements for mandatory flood insurance and restrictions on future development. Work since that time has led to an approximately 1-in-100-year level of protection, removing restrictions on development and requirements for flood insurance. Yet the annualized residual risk for the same home remains high—approximately \$3,000/year. The goal of a 1-in-200-year level of protection for the Natomas area will lower annual residual risk of flooding to \$1,500/year.

When flood policy focuses on flood frequency standards without considering flood risk, this can lead to unintended consequences. A community of 1,000 Natomas-area homes (each with \$300,000 damage in a flood) with a 1-in-70 annual chance of flooding has a total flood risk of \$4.3 million/year ($= 1,000 \times \$300,000/70$). Raising the level of flood protection to 1-in-100 per year reduces this risk to \$3 million/year (\$3,000/year per household). However, if achieving the higher level of flood protection—which meets National Flood Insurance Program standards and avoids development restrictions—increases the number of homes to 5,000, the resulting increase in vulnerability overwhelms the increase in protection and raises residual community flood risk to \$15 million/year ($= 5,000 \times \$300,000/100$). Thus, even with increased flood protection, development-motivated local land use decisions can increase flood risks and state taxpayer liability for flood damages.

However, California faces increasing flood management challenges, with an extensive legacy of short-sighted flood infrastructure decisions, growing human and economic activity in floodplains, growing state liability for flooding, diminished long-term federal and state funding, continued separation of land and

flood management, and climate change. To its credit, the state recently enacted some of the nation's most progressive flood legislation to manage these issues in the Central Valley (Chapters 1, 2, 4). But even these new laws are unlikely to significantly reduce tension between local and state flood management objectives or to effectively limit flood risk. A review of the problems in the current flood management portfolio helps to explain why.

Problems with the Current Flood Management Portfolio

Any portfolio, whether financial or otherwise, needs to be balanced. Flood management in California has had a historical tendency to overinvest in a few tools to increase flood protection, without regard to flood vulnerability. The unintended consequence of these investments is often an increased, rather than a decreased, flood risk. The underpinnings of this problem lie in the policies used to manage risk (Box 6.4).

The main policy instrument for setting flood protection standards in California and the nation is the National Flood Insurance Program (NFIP), administered by the Federal Emergency Management Agency. Communities participating in the NFIP—almost all floodplain communities in California—must restrict new development to elevations at least one foot above the expected water level of the flood with a 1-in-100 chance in any given year (the so-called 100-year flood) (Box 6.5). These requirements, and the precise maps that apply the policy on the ground, are used to define Special Flood Hazard Areas that limit land uses and require flood insurance.

The NFIP policies and maps exert a strong influence on local land use plans, which often seek to barely meet NFIP minimum standards to avoid flood insurance requirements and land use restrictions. Yet this policy has not significantly reduced flood damages (King 2005). In many areas, it has actually increased overall risk by promoting floodplain development.

Current policy failures in managing damaging floods are numerous and complex (Carolan 2005), but can be summarized into the following seven reasons:

1. **Uniform flood frequency standards.** By setting a uniform standard for a frequency of flood protection, NFIP policies fail to include the economic consequences of flooding (flood vulnerability). For example, a 100-year flood in the Natomas area of Sacramento has substantially more risk than a 100-year flood in the town of Modesto, because of the depths of inundation and the value of property behind the levees.

6.5

The 100-year flood

The National Flood Insurance Program requires that communities develop protection from the so-called 100-year flood. The term “100-year flood” is one of the most misunderstood in all of water management. It is the flood with a 1 percent probability (or 1-in-100 chance, thus the name 100-year flood) of being equaled or exceeded in any given year. This does not mean that the 100-year flood will occur every 100 years. Rather, it just means that there is a 1-in-100 chance that it will occur in any given year. Indeed, in some unlucky cases so-called 100-year events have occurred in successive years and occasionally several times within the same year.

Hydrologists use a statistical analysis of the historical record of flows to estimate the flood with the 1 percent probability of occurring. From this analysis, a curve is developed that depicts the relationship between flood magnitude and flood probability: Small floods have a high probability of occurring in any year and large floods have a low probability. What is lost during most debates about who should or should not be included within the boundaries of the 100-year flood zone is the large uncertainty about the 100-year flood itself. Confidence intervals—which indicate the uncertainty of estimates—are always very large for flood probability curves. Thus, a bright line defining the boundaries of the 100-year flood will always be controversial and is hardly warranted.

In addition, every time there is a large flood, the values used to calculate the 100-year event change. An increase in large floods tends to shift the flood probability curve upward. This is why both the 100-year flood and the 100-year floodplain tend to grow after large floods, creating a demand for ever-larger flood protection structures.

2. **Current flood standards too low.** For most floodplain communities, the federal minimal standard of flood protection is insufficient, with high residual flood risks often borne by the state rather than by local authorities and residents. A 200-year standard—which will soon be required for new development in the Central Valley—has many of the same problems as the 100-year standard, because it largely disregards potential damages from flooding and the fact that conditions are rapidly changing. By contrast, Dutch flood standards are 1-in-10,000 years for major urban areas (Box 6.7).
3. **Precise, but inaccurate, flood maps.** Special Flood Hazard Area maps define the precise geographic location and depth of the so-called 100-year flood, but errors in estimates can be



California has relied too heavily on weak levees to protect against flood risk. Photo by California Department of Water Resources.

large, and the statistics are recalculated following large floods (Box 6.5). Large floods in California in 1955, 1964, 1986, and 1997 increased the estimated size of 100-year floods in the Central Valley and North Coast (Box 6.6). The complexity of flow on floodplains and the need for precise topographic data further reduce the accuracy of floodplain maps. Yet the maps legally define which land parcels are “in the floodplain” and which are out, setting insurance rates and land use restrictions.

4. **Neglect of changing conditions.** Methods for calculating the 100-year floodplain exclusively use past hydrology to predict future flood frequency (Milly et al. 2008). This assumption ignores changing conditions within watersheds (typically changes in land use and levees that increase flow peaks) and ongoing changes in climate that will increase flood magnitudes (Chapter 3).
5. **Increased flood elevations from levees.** Levees, particularly those close to rivers, further their own demise. Riverfront levees confine flows to a narrow channel cross-section, eliminating or restricting the flood storage and conveyance functions of floodplains. This significantly raises flood elevations and increases scouring of the levees, raising the likelihood of catastrophic flooding of protected areas (Brookes 1988).

6.6**Updating flood protection in the Sacramento area**

The Sacramento metropolitan area is routinely cited as one of the most at-risk areas nationally for catastrophic flooding. Sacramento chose early in its history to promote the construction of levees closely adjacent to the American and Sacramento Rivers to maximize economic development on adjacent floodplains. These close levees failed frequently in the 1800s and early 1900s, initiating a cycle of levee strengthening and enlarging after each flood (rather than rethinking the wisdom of urbanizing the floodplain).

The U.S. Army Corps of Engineers determined that construction of a multipurpose dam on the American River, upstream of the Sacramento, would provide sufficient flood control to support development of the city. Statistical analysis of the short hydrologic record at the time showed that Folsom Dam, in conjunction with downstream levees, would protect against the 500-year flood. This turned out to be one of a number of misjudgments about flood control for Sacramento. A series of floods occurred after the dam was built, culminating with one in 1986 that came within inches of overwhelming the city. When the statistics of flood probability were recalculated, the 500-year level of protection had been reduced to a 60-year level of protection, putting Sacramento land use under the National Flood Insurance Program's proscriptions.

In 1989, the city, its surrounding unincorporated areas, reclamation districts, and counties formed the Sacramento Area Flood Control Agency (SAFCA). This program has accomplished many things including working with the U.S. Army Corps of Engineers to upgrade levees along the American River and the Sacramento River to meet NFIP minimum standards, purchasing additional flood storage behind Folsom Dam, gaining congressional authorization and funding to modify the Folsom Dam spillway to improve performance during floods, and securing more than \$400 million in state bond funds to upgrade levees on the Sacramento River. To accomplish this, SAFCA required extensive local support to meet cost-sharing agreements. Thanks to an effective outreach program, property owners in the region overwhelmingly supported assessing themselves to cover these costs, and development interests agreed to impact fees to offset future flood control needs created by new developments.

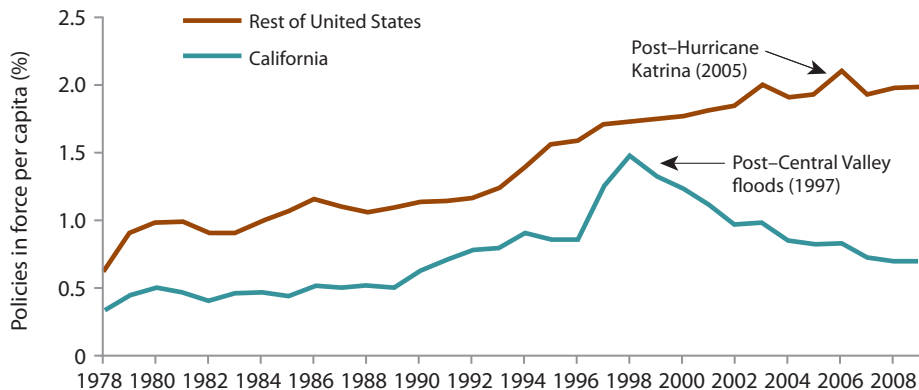
By most measures, SAFCA is a success in tackling its flood issues. The irony is that much of this could have been avoided by an earlier commitment to land use planning that avoids flood hazards rather than relying on very expensive, environmentally damaging infrastructure solutions.

6. **Flood memory half-life.** Perception of risk directly changes pressure for improving flood management. Longer periods of time since a natural disaster reduce the perception of risk—a phenomenon referred to as the “flood memory half-life.” The problem is well in evidence in Californian’s flood insurance coverage behavior, which peaked soon after the 1997 floods—the last large floods within the state—and has declined ever since (Figure 6.7).
7. **Environmental costs.** Flood management infrastructure has imposed a significant and lasting toll on the environment. Thousands of miles of levees have disconnected rivers from their floodplains and prevented the natural adjustments of river channels, altering two fundamental processes needed to sustain river ecosystems (Florsheim, Mount, and Chin 2008). Dams have further enforced this separation. Although conflicts today are often mostly about how much water to extract from the environment, rarely does the discussion turn to how little environment is left as a result of flood management.

These seven factors combine to make it difficult to effectively manage flood risk sustainably with the present mix of policies.

Figure 6.7

California flood insurance coverage has been falling since the 1997 floods



SOURCE: Authors’ calculations using flood insurance data from the National Flood Insurance Program and population data from the California Department of Finance and the U.S. Census.

NOTE: The figure shows insurance policies in force from 1978 to 2009.

Updating the Flood Portfolio

To effectively manage future flood risk, California should move away from overdependence on the NFIP to guide flood planning and design and move toward more risk-based approaches. With its 2007 legislative package, the state showed that it can go beyond federal flood policies. However, the change made then was incremental: Flood protection requirements in the Central Valley were doubled, but the emphasis continues to be on flood frequency rather than flood risk. To modernize flood protection, the state should fundamentally break with the NFIP approach and focus on risk.

A balanced flood management portfolio should contain the following key elements.

1. **Sustainable finance.** Flood protection is expensive and state and federal funding sources are inadequate (Chapter 2). Fee-based approaches, based on the value of structures at risk in floodplains and the likelihood and depth of a flood, would better allocate the costs of flood management to its beneficiaries.³⁰ Local funding is essential both for accountability and because federal and state funding will be severely limited well into the future. For decades, much of California has placed itself at risk every winter, waiting in vain for resurgence in federal flood control funding. It is now clear that federal funding is unlikely to be substantial or timely.
2. **Local responsibility.** Flood management needs to move from the assumption of state liability for flooding toward increased local responsibility for risk management. Although state flood legislation in 2007 created potential shared liabilities between the state and local communities that promote development in flood prone areas, the terms of this new law are sufficiently ambiguous that it is unlikely to compel communities to invest in reducing risk. Moreover, this legislation applies only to the portions of the Central Valley protected by the Sacramento–San Joaquin Flood Control Project. Two steps should be considered:

30. Under California law, “benefit assessments” are the appropriate vehicle. Today, benefit assessments in some areas (such as SAFCA) rely at least in part on the likelihood and likely depth of flooding, but this practice should be extended.

- a. Develop mandatory risk-based flood insurance requirements for all properties within the 500-year floodplain.³¹ As with fire hazards, mandatory insurance is the most direct way to reward local communities for their flood management investments and decisions, as well as to prepare to cover their residual risks.
 - b. Provide annual flood risk disclosures to all property owners within the 500-year floodplain. Disclosures can help maintain public awareness and increase the likelihood of maintaining insurance. These disclosures should include flood frequency and depth of flooding and can build on efforts recently begun with the flood legislation package of 2007, which requires that DWR provide annual flood risk notices to Central Valley landowners in areas protected by levees.
3. **Rebalanced portfolio.** Changing economic and climate conditions, along with improvements in scientific capabilities, should help improve the mix of flood management activities. Greater emphasis should be placed on:
- a. Vulnerability reduction: making structures less vulnerable to flooding, rather than focusing solely on reducing flood frequency;
 - b. Better levee maintenance and reliability: conducting systematic periodic assessment, maintenance, and improvement of flood defenses;
 - c. Reservoir reoperation: using new forecasting and modeling tools to operate multipurpose reservoirs for improved flood protection;
 - d. Expanded flood bypass capacities and setback levees: making greater use of floodplains to store and convey floods, rather than relying on simply raising levees;
 - e. Sacrificial flooding: allowing rare flood peaks to spill into some lower-value floodplain areas to reduce flood levels elsewhere;

31. Within the Central Valley, there is little difference between the 500- and 1,000-year floodplain, so a 500-year insurance mandate would effectively cover most structures at risk of flooding.

- f. Expanded purchases of flood easements and outright land acquisitions: supporting the expansion of bypasses and areas available for sacrificial flooding; and
 - g. Mitigation payments to county governments: compensating local governments for the forgone tax revenues from forgone development of lands in new bypass and sacrificial flooding areas.
4. **Risk-based planning.** Current frequency-based planning should shift to risk-based planning to be economically viable. Risk-based planning ensures that investments in flood management create the greatest net reduction of risk and flood management cost. This approach, if done properly, helps prioritize investments of limited funds. When state and federal resources are invested in flood management, there is strong political pressure to “spread the money around” to appear equitable. Frequency-based flood management encourages diffuse investments because various stakeholders inevitably argue about what level of protection they should receive. By quantifying the costs and benefits of flood management, risk-based methods help focus on investments that are cost-effective. SAFCA (Box 6.6) provides a model for risk-based local assessments: Its fees have been based largely on flood depth, allowing it to raise more funds from areas with the greatest likely reductions in flood risks.³²
5. **Adaptive capacity.** One consequence of frequency-based planning is emphasis on satisfying the minimum federal standard for level of protection. As discussed above, this standard, based on a short historical record, ensures future crises as changing conditions increase local flood vulnerability and exceed the design flood capacity. Communities that have invested in a 100-year level of protection must regularly undergo the disruption of being mapped in or out of the 100-year floodplain, with increases in insurance requirements, disruptions in economic development, and expensive “fixes” to meet the revised level of protection. To avoid this,

32. This differentiated fee structure fell within SAFCA’s interpretation of Proposition 218 requirements.

risk-based planning must also incorporate the capacity to adapt to changing future conditions. This involves building more robust structures in some areas, providing room for the river in others, identifying locations for storing floodwater on floodplains, and negotiating changes in reservoir flood operations. As in the Netherlands, California should require periodic assessment of flood protection structures and flood vulnerabilities and hydrology, without waiting until after major floods have occurred (Box 6.7).

6. **Integrated environmental objectives.** It is not enough to simply seek to mitigate damage to the environment from flood management. Environmental mitigation approaches have failed to halt the decline of ecosystems and native species (Chapter 5). Rather, the goal of future flood management design, construction, and operations should be to *improve* ecological conditions to meet a broad range of environmental services provided by rivers and their floodplains. Improving services such as groundwater recharge, nutrient and pathogen reductions, recreation, improved soil moisture and fertility, temperature and airborne particulate reductions, commercial fisheries, and native biodiversity are compatible with modern flood management and should no longer be viewed simply as costs (Box 5.1). Recent flood management on the Napa River provides good examples of urban flood management that supports significant riparian and wetland environmental improvements (Box 6.8).
7. **Integrated water supply and flood management.** Better coordination of reservoirs for flood and water supply operations can expand both services (Georgakakos and Graham 2008). Particularly with climate warming—with more runoff in winter and less in spring—storing water for droughts in aquifers, rather than in reservoirs, provides more reservoir space to capture winter precipitation (Tanaka et al. 2006). Conjunctive operation of surface and groundwater for floods and water supply can also improve ecosystem function. For instance, seasonal flooding of parts of the Yolo Bypass and

other areas may improve spawning conditions for native fish while recharging groundwater basins and reducing flood risk in nearby urbanized areas.

These seven elements would go far toward meeting the challenge of managing floods for an expanding population and an uncertain future climate. Reform of California's flood policy should apply beyond the Central Valley to other flood-prone areas of California, including the Los Angeles Basin, the Bay Area, and North Coast Rivers. Regionally integrated approaches tailored to regional and local conditions will be best suited to implementing this strategy. The Netherlands—another developed economy with high flood risk exposure—employs many of these elements in its flood management (Box 6.7).

6.7

The Netherlands' approach to flood management

The Netherlands is a flood-prone region where flood management receives more attention and sustained funding than in California. Maintenance of flood structures is supported by taxes on local lands, and the national government supports national flood infrastructure. Regional flood standards are risk-based and determined by a national effort, with the levee reliability of each area determined based on a balancing of flood protection costs and flood damage vulnerability and frequency (Woodall and Lund 2009; van Dantzig 1956). Each levee undergoes a rigorous independent evaluation every six years, with systemwide plans developed every 12 years (Hessel Voortman, personal communication 2010). Although California has a levee certification process, there are no set frequency requirements for reevaluation of levees in California, just evaluations of maintenance to meet federal and state standards. Aside from the technical merits, periodic recertification of levees provides a consistent public policy reminder of the importance and condition of local flood protection infrastructure, helping to defeat the flood memory half-life. Dutch risk-based levee standards, explicitly balancing protection costs and risk reductions, also provide much higher levels of flood protection than are common in California. Major urban areas are protected to the 0.01 percent annual level (a 1-in-10,000-year flood), with more rural areas protected to lower levels. In recent years, growth of population and property values in the Netherlands, as well as anticipated sea level rise, has led to a call to raise these levels of protection (Eigenraam 2006; Voortman and Vrijling 2004). Over time, Dutch flood management also has responded to changes in societal desires to improve ecological functions, with greater emphasis on developing more ecological "room for the river" (Deltacommissie 2008). Decades of attention to flood management have also led to significant scientific and technical advances (Disco and van der Ende 2003).

6.8

Flood protection with environmental benefits along the Napa River

The Napa River, which runs through downtown Napa, has a long history of flooding. Historically, the lowest reaches of the river meandered across a broad floodplain that merged with the tidal marshes of San Pablo Bay, part of the San Francisco Estuary. High flood flows on the river and its main tributary, Napa Creek, have subjected residents of downtown Napa to more than 20 significant floods since the city was founded. For more than a century, the town used traditional methods to manage floods, involving construction of levees, floodwalls, and dikes to constrain the river to a small footprint.

For many years, the town sought improvements in flood protection through Congress. Although Congress authorized a project for Napa in 1965, the residents refused to tax themselves to fund the local match. However, floods can be a great motivator. Following major floods in 1986, 1995, and 1997 that severely damaged the city, and a near-miss flood in 1998, the city passed a measure in March 1998 to fund a flood control project (highlighting the importance of the flood memory half-life; see the text).

The Napa River Flood Project's design is innovative. It restores a wide range of ecosystem services, including recreation and support for native biodiversity. Originally, the U.S. Army Corps of Engineers proposed a traditional approach involving enlarging existing levees and floodwalls and straightening the river. The city's residents resisted this effort and developed a plan to reduce flood risk while improving the natural functions of the river. This involved removing levees in the lowest part of the project and reconnecting the river to its historical tidal marsh. The project also included creating a flood bypass channel, replacing bridges to reduce constrictions, and giving the river room to adjust its channel without affecting flood infrastructure.

The project has received many awards and is held up as an example of restoring key ecosystem attributes while lowering flood risk. The project is not without its problems, however. It has not been completed, principally because of large delays in federal funding. In addition, the project, as currently designed, provides only the bare minimum 100-year level of protection required by the National Flood Insurance Program, a level of protection insufficient for urban flood control projects. Finally, there are no plans to adapt to rising sea level and changing runoff patterns in the basin. Floods will return to Napa and, although less frequent, may be more devastating.

Portfolios Across Sectors: Integrated Water Management

Many tools are available individually and collectively to address California's water supply, water quality, and flood risk problems. However, California is not making adequate use of some of the most cost-effective tools or mixtures of tools. To be more effective, these diverse tools also should be used across larger scales. Integrated, basin-scale approaches—which jointly consider supply, quality, floods, and related land use at the level of the watershed—are often necessary to reap the benefits of modern management tools. Integration needs to address two types of fragmentation that now plague California's decentralized system for water and land management. Geographic fragmentation results from numerous agencies making decisions that affect the whole watershed, and functional fragmentation results from numerous agencies making decisions on only one piece of the supply-quality-flood-land-use puzzle.

As noted above, the state has attempted to promote regional integration in recent years, primarily through the allocation of grants to agencies working in partnerships. Although this financial carrot approach has encouraged some new forms of cooperation and collaboration among local entities, it suffers from the need to distribute large sums of cash, which has kept the focus of partnerships on capital projects that agencies want to build.³³ To achieve real functional and geographic integration, California needs to develop a management framework that requires regional coordination in water and land resource planning. As we discuss further in Chapter 8, regional stewardship authorities, organized at the scale of the state's nine water quality basins, could provide this organizing framework. One prototype for this model is the Santa Ana Watershed Project Authority, which operates at the scale of the Santa Ana Regional Water Quality Control Board (Region 8) and which has aimed to integrate a wide range of water and land use planning functions (Box 6.9).

Information and Analysis: What Needs to Improve?

More comprehensive, integrated portfolio management requires better information and better analysis. Despite being a center of the world's emerging information economy, California does not have adequate information on water to meet current and future challenges. In addition, the state's policy and

33. To wit, it is sometimes said that IRWM, the acronym for Integrated Regional Water Management, stands for "I really want mine."

6.9

Santa Ana Watershed Project Authority

One example of the management of diverse interests at the watershed scale comes from the Santa Ana Watershed Project Authority (SAWPA), a joint powers authority established in 1974 to manage water supply and water quality in the Santa Ana watershed.

The Santa Ana watershed covers 2,800 square miles, making it the largest urban watershed in Southern California. This historically agricultural watershed, once filled with large dairies and fruit orchards, is undergoing rapid urban expansion. After many years of conflicts over changing demands for water quality and supply, the five large water districts that serve the watershed developed SAWPA. Initially, the goal was to deal with water supply and waste and stormwater treatment in an integrated fashion. Today, SAWPA's mission has expanded to include habitat restoration, invasive species management, and flood control, in recognition that these efforts are integral to the water supply and quality management missions.

SAWPA faces many challenges. To meet an annual water demand of approximately 1.4 million acre-feet, SAWPA and its member agencies have initiated some of the state's most progressive water recycling and reuse programs, with extensive conjunctive use of groundwater basins. The watershed has significant and widespread problems with high-salinity waters, which constrain recycling and reuse efforts. To manage this, SAWPA has coordinated and helped fund the state's most elaborate salt capture and removal system, the Santa Ana Regional Interceptor line. SAWPA has also initiated programs to capture, treat, and store urban stormwater. In addition, one of the largest flood control facilities, Prado Dam, is now operated as a water storage facility that recharges groundwater within Orange County. To address poor water quality on the main stem of the Santa Ana River, SAWPA members have developed extensive treatment wetlands. Finally, SAWPA has coordinated extensive efforts to manage invasive species (the giant reed, *Arundo donax*, in particular), and to improve aquatic habitat and recreation at the watershed scale.

No one within the Santa Ana watershed is under the illusion that SAWPA has resolved all of the watershed's problems. Many of its programs are either in the planning stage or relatively new, so their effectiveness cannot be evaluated. Yet this approach—coordination, cooperation, and integration of water agencies to pool resources and manage water at the basin scale—is one of California's best models for integrated water management.

decisionmaking processes are poorly prepared to use technical and scientific information. The problem partly stems from inadequate data collection, which reflects opposition by stakeholders who fear that making this information available will lead to an increase in regulation. This is the case with groundwater in much of the state, for instance.

But state agencies also put too little effort into analyzing and making available information that could easily be assembled. For instance, there is no centralized database for urban water and wastewater rate schedules, even though this information is publicly available. To date, analysts have relied on periodic reports from a private consulting firm, Black and Veatch, to understand trends and patterns in rate structures. The state could easily require that utilities report changes in rate structures and post this information; ideally, state analysts would also regularly assess rate structure trends. As another example, no centralized database exists on the state's water market. Instead, various state and federal agencies keep track of the transfers that they oversee, and a private firm, Stratecon, publishes information on some transfers in a monthly periodical, *Water Strategist*. Although it would be straightforward for the state to develop a centralized database on the water market, efforts to do so as part of the CALFED program founded in the early 2000s and have not been renewed.

In general, improving water information will require more standardized data collection. Much detailed information exists at the level of decentralized water management entities. But given that much portfolio analysis needs to occur at regional and statewide levels, this information needs to become available in a standard format so that it can be aggregated to the appropriate scale. For example, estimates and projections of water demands, supplies, and costs should be done using common standards. Given the limited technical expertise available to the state in this matter, data collection standards and methods (including software) should probably be developed by a committee led by local and regional agencies, which will make most use of these data, with inputs from other interested parties.³⁴

Fortunately, California does not need to start from scratch in this endeavor. The state already has a very useful tool for reporting on long-term urban water demand and supply planning—Urban Water Management Plans (UWMPs). These plans, prepared every five years by all large and medium-sized urban

34. A parallel is the development of many federal highway design standards, where state transportation agencies have played a leading role.

utilities (at least 3,000 connections) cover close to 90 percent of the population, and they require that utilities report on a standard set of issues.³⁵ Unfortunately, the ability to aggregate the data to the regional or statewide level is now hampered by nonstandard reporting (Hanak 2010). For example, demand reductions from conservation are not calculated in a standardized way in these plans, nor are the levels of confidence in projected new supply sources. With readily accessible, standardized information, UWMPs could form a useful foundation for regional integrated planning, along with flood management, water quality, and land use plans, as well as state water and resource plans. Similar efforts could apply to agricultural water supplies. Senate Bill X7-7, one of the bills in the water legislation package passed in 2009, requires that DWR develop standardized reporting forms for UWMPs and expands the number of agricultural agencies that will prepare Agricultural Water Management Plans. This effort is an important first step in improved data reporting, even though reporting private groundwater pumping is still not required by law. For this effort to be effective, DWR will also need to monitor the reports for data quality, not just completeness, as it currently does (Hanak 2010).

Of course, data without analysis are almost useless. Local, regional, and statewide modeling and analytical capabilities need to be further developed so that the cost and service performance of particular portfolio solutions can be better documented, understood, and explored (Rosenberg et al. 2007; Rosenberg, Howitt, and Lund 2008; Harou et al. 2009). Advances in modeling and analysis are continuous, with the optimal lifetime of an analytical tool being somewhere between five and 15 years, depending on the application. California should be upgrading and replacing old modeling software and methods much more quickly than it now does. These tools should represent and integrate many local, regional, and statewide options. With a proper state framework and information standards, high-quality local plans and information can be better integrated regionally, perhaps under the auspices of new regional stewardship authorities. Functioning regional plans can then become the basis for truly integrated resource plans and policies at the state level. Having such capability would entail some technical controversies but would dispel many myths and make it easier for policymakers to consider and explore the important technical and scientific aspects of California's water problems.

35. In addition, California's Urban Water Conservation Council, a membership organization, collects and analyzes data from its 233 water utility members to assess compliance with implementing agreed-upon urban water conservation practices. Although these data are posted online, they are not available in a format that facilitates analysis of trends or comparisons across agencies.

Priorities for Portfolios in Water Management

California is not helpless in facing its chronic problems of water scarcity, water quality, and flooding. More effective, robust, and cost-effective solutions to these problems are available by orchestrating a range of options at local, regional, and statewide levels. These “portfolio” solutions combine the strengths of individual options but require a higher level of analysis and integrated decisionmaking than is currently common in the state.

Water Supply Priorities

Water supply management has seen the most progress in implementing portfolio approaches, as numerous nontraditional tools have been tapped to cope with increasingly tight water supplies. Expanded efforts are especially needed in three areas: urban conservation, groundwater banking, and water marketing.

Urban conservation has the potential to play a major role in mitigating the effects of reduced export capabilities from the Delta and supply losses that may result from dry forms of climate change. Water rate reform, using tiered rates with variable base allowances, can promote conservation in a flexible and fiscally responsible way.

The state should also work to loosen institutional barriers to groundwater banking and water marketing, two essential tools for adapting to water scarcity. As discussed in Chapters 7 and 9, we propose that the state establish criteria for integrating groundwater and surface water and for managing groundwater withdrawals and allow local entities to develop implementation plans. In Chapter 7, we also discuss solutions to improve the functioning of the water market. These include streamlined environmental reviews and the creation of an independent system operator, modeled after the energy sector, to serve as a water transfer clearinghouse. With better-functioning water markets and more effective environmental reconciliation, agricultural water conservation will increase in response to water scarcity and incentives to transfer water to agricultural, urban, and environmental activities in which water has a higher economic value.

Water Quality Priorities

Water quality management in California has been most successful in reducing pollution from point sources (by treating wastewater and industrial waste) and in removing pollution from drinking water (by treating water before use). To

reduce impairment and regain environmental and recreational uses of water bodies, California must make greater headway in two areas: preventing harmful chemicals from entering the environment and meeting performance targets for reducing discharges of nonpoint-source pollutants.

To meet the first goal, the state should continue to build on the successful model of Proposition 65, the Safe Drinking Water and Toxics Enforcement Act of 1986. Proposition 65 shifts the burden of proof to manufacturers, relies on multiple data sources, and allows private sector enforcement for some toxins that affect human health. The state's new Green Chemistry initiative, which seeks to make information available on chemical ingredients in products and to reduce the lifecycle effects of chemicals, is one promising avenue.

To meet the second goal, California should embrace water quality trading, which can help lower the cost of reducing nonpoint-source pollutants. California already has a successful model of trading to reduce selenium from agricultural runoff in the Grasslands area of the western San Joaquin Valley. As with groundwater management, local entities should be given the flexibility to develop implementation solutions to meet state performance criteria.

Federal actions also will be important for cost-effective water quality management. In particular, more flexibility is needed to enforce water quality standards under the Clean Water Act in cases where natural conditions such as nutrients and temperature preclude effective management solutions.

Flood Management Priorities

In the 2007 flood legislation, California broke with federal policy by setting higher protection standards for new development in the Central Valley. But the focus is still largely on improving flood protection infrastructure, using levees and reservoirs to limit the frequency of flooding. And despite \$5 billion in recent state bond funds, California's flood protection system remains woefully underfunded.

To limit the growth of flood risk—or the average economic losses from flooding—California should focus more on reducing flood vulnerability. This means limiting the location of new development in flood-prone areas, improving building codes, expanding mandatory flood insurance requirements, and improving flood risk disclosure. Higher local contributions also are needed for flood protection investments, and properties facing higher risks should pay higher fees—a model already in use in the Sacramento area. To make the most of scarce flood investment dollars, both the state and federal governments

should allocate funds based on cost-effectiveness, which depends not only on the costs of investments but also on the value of assets being protected.

The flood portfolio also should be expanded to include more environmentally beneficial protection measures, such as bypasses and levees set back farther from the river to expand the floodplain. Such tools can provide multiple benefits and are often cost-effective. They will require compensation of local landowners and local governments for the loss of revenues from forgone development.

Finally, flood policy should apply beyond the Central Valley to the many other flood-prone areas of California, including the Los Angeles Basin, the Bay Area, and the Central and North Coasts.

Integrating Actions

To realize many of the gains in water management, it will be necessary to overcome the geographic and functional fragmentation that characterizes California's highly decentralized system. Integration at the scale of watersheds, with coordinated planning of water supply and quality, flood management, and land use, is essential to meet objectives for human and environmental water uses. The current voluntary approach to integrated management—which entices local entities to collaborate in exchange for state bond support for infrastructure projects—is not very effective. As discussed further in Chapter 9, we recommend the creation of regional stewardship authorities, either replacing or supplementing existing regional water quality control boards, to coordinate and focus the efforts of local agencies.

Better information and stronger analytical tools will be needed to support these goals. The state has an interest in the collection and development of local, regional, and statewide information, as well as in regulations and incentives that foster the development of effective portfolios. Without such information and institutional prodding, water decisionmaking and conflicts will remain more difficult, expensive, and time-consuming to resolve. In the next chapter, we further explore ways to balance water management for economic and environmental sustainability, focusing in particular on using and strengthening the state's legal framework for water allocation and water system finance—keys to managing water as a public commodity.

