I

INTRODUCTION

> It took me eight days before I could find the entrance of the Sacramento, as it is very deceiving and very easy to pass by.
>
> JOHN SUTTER, *The Diary of Johann August Sutter,* 1838–1839 entry

Throughout the world, and particularly in the American West, people are learning how to remanage natural resource and environmental systems, which they had thought of as fully developed and sustainable. In many cases, the old assumptions are proving false. External forces such as sea-level rise, climate change, economic globalization, population growth, and rising concern for the natural environment all impose changes on the management of these systems. In some cases, the internal dynamics, however well intentioned, are also proving unsustainable—with outcomes such as soil erosion, accumulation of pollutants in soils, and groundwater deterioration imposing changes in management over time. This complex confluence of changes in circumstances and expectations should encourage societies periodically to rethink how to manage natural systems. Yet such questioning can be difficult when people have many years of experience and investment in the past.

The Sacramento–San Joaquin Delta is part of the largest estuary on the West Coast of the Americas, providing a home to roughly 50 species of fish and close to 300 species of birds, mammals, and reptiles. The Delta is also the largest single source of California's water supply, channeling water from Northern California's watersheds to two-thirds of the state's households and millions of acres of southern Central Valley farmlands. Locally, the Delta also supports a productive agricultural and recreational economy.

The Delta's ecological, water supply, and local land use functions are in crisis, with crashing populations of native fish species and increasing risks of a catastrophic failure of fragile levees—an event that could severely disrupt the state's water supply as well as local activities. Because the current water supply system has helped change the Delta ecosystem in unfavorable ways, water exports are also susceptible to cutbacks, to protect endangered fish species. This combination of extreme risks—to the state's water supply, the estuarine ecology, and the local economy—make the Delta the foremost water management problem facing California.

Strategies to manage the Delta to satisfy competing interests have been discussed and debated for almost 100 years, at times leading to acrimonious divisions between Northern and Southern California, environmental and economic interests, and agricultural and urban sectors. Recently, the Delta has again taken center stage in debates on California water policy. Research and actual levee failures have exposed the Katrina-level fragility of 1,100 miles of levees, on which both Delta land uses and water supply systems currently depend. In addition, dramatic population declines have occurred among several fish species that depend on the Delta. As awareness of these risks has heightened, it has also exposed weaknesses in the institutional framework for governing the Delta watershed. By late 2004, the state and federal government sponsored a stakeholder-driven process known as CALFED—established a decade earlier to mediate conflict and to "fix" the problems of the Delta—had begun to unravel. As this informal truce among competing interests eroded, lawsuits have filled the gaps left by a lack of consensus on management strategies and options. For the past 70 years, California's official policy has been to maintain the Delta as a freshwater system through a program of water flow regulation, supported by the maintenance of agricultural levees. This approach now appears near or past the end of its useful life, given the deterioration of the Delta's ecosystem and levees, as well as the rising consequences of levee failure.

This book is about finding better solutions to Delta problems. We do not pretend to offer a perfect, comprehensive solution; 100 years of history would argue that kind of solution is unlikely. Indeed, it may be that different Delta strategies are appropriate for different periods in California's development. Instead, our aim is to launch a serious, scientific search and comparison of potential long-term strategies, and provide some broad guidance for the coming decades. This analysis is wide-ranging and integrated,

with a focus on the future and best management of the Delta and its landscape and inflows for environmental and economic purposes.

WHAT IS THE DELTA?

The Delta is a web of channels and reclaimed islands at the confluence of the Sacramento and San Joaquin rivers. It forms the eastern portion of the wider San Francisco Estuary, which includes the San Francisco, San Pablo, and Suisun bays, and it collects water from California's largest watershed, which encompasses roughly 45 percent of the state's surface area and stretches from the eastern slopes of the Coast Range to the western slopes of the Sierra Nevada. It resembles other deltas of the world in that it is at the mouth of rivers, receives sediment deposits from these rivers, and was once a vast tidal marsh. The Sacramento–San Joaquin Delta fundamentally differs from other delta systems, however, in that it is not formed primarily by sediment deposits from upstream. Instead, it is a low-lying region where sediment from the watershed commingled with vast quantities of organic matter deposited by tules and other marsh plants. For some 6,000 years, sediment accumulation in the Delta kept pace with a slow rise in sea level, forming thick deposits of peat capped by tidal marshes (Shlemon and Begg 1975; Atwater et al. 1979; Malamud-Roam et al. 2007). A century and a half of farming has reversed this process, creating artificial islands that are mostly below sea level, protected only by fragile levees (Drexler et al. 2007). Today, those who drive through the Delta see mainly huge tracts of flat, prosperous farmland intersected by narrow channels populated by recreational boaters.

Geographically, the area known as the "Legal Delta" lies roughly between the cities of Sacramento, Stockton, Tracy, and Antioch (p. xix). It extends approximately 24 miles east to west and 48 miles north to south and includes parts of five counties (Sacramento, San Joaquin, Contra Costa, Solano, and Yolo). At its western edge lies Suisun Marsh, an integral part of the Delta ecosystem. At its southern end, near Tracy, motorists pass over two major pieces of California's water infrastructure—the Delta-Mendota Canal and the California Aqueduct. These and several smaller aqueducts, built between the 1930s and the 1960s, deliver water from Northern California rivers to cities and farmland in coastal and Southern California and the San Joaquin Valley. The Delta is considered the hub of the state's

DELTA MISNOMERS

There is a long tradition in the Delta of improperly naming its physical features. At the top of the list is the term "Delta." Throughout the rest of the world (with a few exceptions, such as the Okavango Delta), deltas are formed where rivers disgorge into open bodies of water, leaving a prism of sediment, often of a shape similar to the Greek symbol Δ. The Sacramento–San Joaquin "Delta" does not qualify as a traditional delta, since it is formed at the tidally influenced confluence of two large floodplain rivers. The second and third most common misnomers are the terms "levees" and "islands." Levees are earthen embankments that hold back water during floods. The "levees" of the Delta are truly *dikes* that hold back water all the time. Similarly, islands are lands of positive relief surrounded by water. The Delta's "islands" are reclaimed lands that form topographic depressions surrounded by water. In this regard, they are *polders* instead of islands. Despite these differences, we use the terms "Delta," "levee," and "island" to match local convention in California. The Dutch, whose delta landscape employs many dikes to maintain their polders, have a different and more authoritative usage.

water supply because it is used as a transit point for this water. This role has significantly influenced Delta management policies, which aim to keep Delta water fresh.

Today, the Delta supports a highly modified ecosystem. It resembles the Delta of the past only in that some of the original species, such as delta smelt and Chinook salmon, are still present, albeit in diminished numbers. Invasive organisms, from plants to fish species, now dominate the Delta's steep-sided channels and long-flooded islands (mainly Franks Tract and Mildred Island).[1] Most of the native fish either migrate through the Delta (e.g., Chinook salmon, steelhead, and splittail) or move into it for spawning (delta smelt and longfin smelt). Resident native fish are present mainly in areas strongly influenced by Sacramento River flows. Recent years have seen spectacular declines in salmon populations (often called "anadromous" because they live in ocean water and move inland to spawn), the delta smelt, longfin smelt, and other open-water or "pelagic" species. Habitats in marshlands and along the banks of rivers ("riparian" areas) have been reduced to small remnants in the Delta, although agricultural lands are important winter foraging areas for sandhill cranes and various waterfowl (Herbold and Moyle 1989).

WHY THE DELTA MATTERS TO CALIFORNIANS

Most Californians rely on the Delta for something, whether they know it or not. About half of California's average annual streamflow flows toward the Delta. Most Californians drink water that passes through the Delta, and most of California's farmland depends on water tributary to the Delta.[2] In addition, increasingly, people are building homes in the Delta, perhaps not realizing the risks to their property and lives from living near or below sea level behind undersized and insufficiently maintained levees. Table 1.1 summarizes the many ways in which California's regions receive services from the Delta.

Clearly, the Delta is not merely a hub for water supply. It is also a center for important components of California's civil infrastructure (Figure 1.1). The electricity and gas transmission lines that crisscross the region serve many parts of the state. The Delta is also used for the underground storage of natural gas to accommodate peak wintertime demands. Furthermore, the Delta hosts several transportation lines. California's major north-south highway (I-5) goes through its eastern edge, and two commuter routes—SR 4 and SR 12—cross its southern and central portions, respectively (Figure 1.1). Several rail lines pass through the heart of the Delta, as do the deepwater ship channels leading to the ports of Stockton and Sacramento. In addition, aqueducts and canals conveying water to several west-of-Delta water utilities—including the East Bay Municipal Utilities District and the Contra Costa Water District—also pass through parts of the Delta. Two power plants are at the Delta's western edge in Antioch and Pittsburg.

As noted earlier, the Delta also provides crucial habitat: Many of California's fish species live in or migrate through it. Moreover, the Delta is valued for its aesthetic appeal and support of recreational activities. Its proximity to population centers in the Bay Area, Sacramento, and northern San Joaquin Valley makes it an attractive destination for boating, fishing, hunting, and ecotourism. The Delta's 635 miles of boating waterways are served by 95 marinas containing 11,700 in-water boat slips and dry storage for 5,500 boats. In 2000, there were an estimated 6.4 million boating-related visitor-days, with 2.13 million boating trips. Recreational boating is expected to grow to 8.0 million visitor-days by 2020 (Department of Boating and Waterways 2002). Fishing is also a popular activity (Plater and Wade 2002), as is duck hunting in the Suisun Marsh.

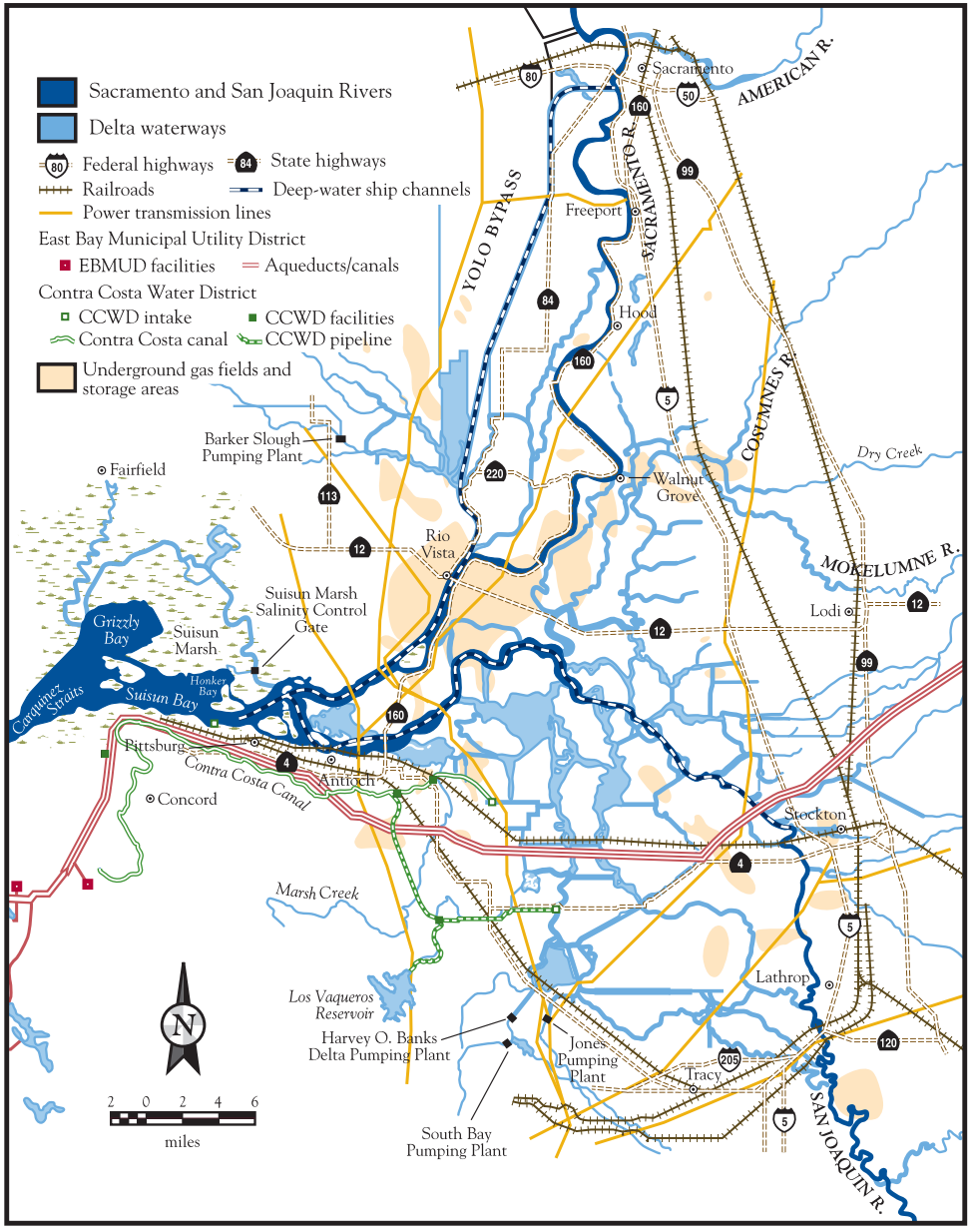

FIGURE 1.1 Infrastructure in the Delta.

TABLE 1.1 *Services Supplied by the Delta Region to Areas of California*

Delta Service	*Benefiting Region*			
	North of Delta[a]	In-Delta[b]	South of Delta[c]	West of Delta[d]
Agricultural land use		✓		
Urban land use		✓		
Ecosystem nutrients and support		✓		✓
Migration routes for salmon and other fish	✓	✓	✓	✓
Water supply	✓	✓	✓	✓
Recreation (boating, fishing, hunting, ecotourism)	✓	✓	✓	✓
Commercial shipping	✓	✓	✓	✓
Natural gas mining and power generation	✓	✓	✓	✓
Electricity and gas transmission and gas storage	✓	✓	✓	✓
Road and rail connections	✓	✓	✓	✓
Salt, waste, and drainage disposal	✓	✓	✓	
Water supply right-of-way				✓

[a]North of Delta includes the Sacramento Valley.

[b]In-Delta includes Delta islands.

[c]South of Delta includes Southern California and the eight-county San Joaquin Valley.

[d]West of Delta includes the San Francisco Bay Area (including Contra Costa County).

The Delta also serves as a vast drainage area for polluted agricultural and urban runoff. This runoff contains a variety of surplus and residual pesticides and nutrients, in addition to contaminants leached from the soils of upstream regions. Drainage from within the Delta contains dissolved organic compounds from the islands' peaty soils, which increase water treatment costs and drinking water quality risks. Sacramento Valley drainage includes mercury and other wastes from historic mining activities, and San Joaquin Valley agricultural drainage includes salts originating in the soils from its west side and sea salts and agricultural drainage intruding into irrigation supplies. Retaining such wastes locally would cause great expense and impairment within the source regions, but allowing them to flow into the Delta creates water quality problems for human and environmental uses within the Delta and beyond.

Finally, the Delta provides land. Until recently this land had been used predominantly for agriculture. Today, however, the Delta's land, as well as its water, has come into greater demand for urban, environmental, and recreational uses.

THE DELTA IN CRISIS

Concerns for the continued provision of services from the Delta involve several issues:

- Land subsidence, sea-level rise, and changes in climate make Delta levees increasingly vulnerable to failure from earthquakes, floods, and other causes.
- Endangered species and fisheries have continued to decline, and disruptive nonnative species continue to invade.
- Delta water quality remains at risk from salts entering from the ocean and the San Joaquin Valley's agricultural drainage, as well as from pesticides, metals, and other contaminants from agricultural and urban lands.
- Regional population and economic growth have increased pressure to urbanize Delta lands near major transportation routes and urban centers. This "hardening" of Delta lands simultaneously raises the costs of flood risks and reduces the flexibility of land management options.

Awareness of these issues has intensified in recent years, leading many to question the viability of current policies for the Delta. Indeed, by several key criteria, the Delta is now widely perceived to be in crisis. One aspect of the crisis is the health of the levees. The devastating effects of Hurricane Katrina on levees in New Orleans galvanized public attention on the fragility of the Delta's levee system, where close calls occur with some frequency; for example, a Jones Tract levee broke in June 2004. Recently, the Department of Water Resources (DWR) has publicized the economic consequences of a catastrophic levee failure caused by a large earthquake. One scenario, which envisaged 30 levee breaches and 16 flooded islands, predicted that water exports would be cut off for several months, that shipping to the

Port of Stockton would be cut off, and that there would be disruptions of power and road transportation lines (Snow 2006). The total cost to the economy over five years was estimated at $30 to $40 billion. A similar study of a 50-breach scenario that focused only on the costs to water users, put the annual cost of a shutdown of water exports at the pumps at $10 billion (Illingworth et al. 2005).

The second aspect of the crisis is the health of Delta fish species. In the fall of 2004, routine fish surveys registered sharp declines in several pelagic species, including the delta smelt, a species endemic to the Delta and listed as threatened under the Endangered Species Act (ESA). Subsequent surveys have confirmed the trend, raising concerns that the delta smelt—sometimes seen as an indicator of ecosystem health in the Delta—risks extinction if a solution is not found quickly (Figure 1.2).

The third aspect of the crisis is institutional. The CALFED process that has been responsible for coordinating Delta solutions since the mid-1990s has faced serious problems since late 2004. CALFED's failure to anticipate funding and disagreements among stakeholders on some key elements of its program has contributed to a loss of confidence in its institutional framework (Little Hoover Commission 2005). Since the summer of 2006, the California Bay Delta Authority—the body responsible for coordinating CALFED activities—has operated within the Natural Resources Agency, without an independent budget. Thus, the strong leadership and financial resources needed to address the Delta's problems are currently lacking. In this institutional vacuum, federal court decisions under the Endangered Species Act are now determining the conditions for water management. The state's recently completed Delta Vision process (Isenberg et al. 2008a, 2008b; Natural Resources Agency 2009) has signaled that state government and many stakeholders are aware that Delta policies are unsustainable and potentially catastrophic, and that they show a willingness to consider some major policy changes.

RESPONDING TO THE CRISIS

Recognition of the Delta crisis has led to appeals to pursue several very different management strategies. The collapse of Delta fish populations has prompted some environmentalists to call for cutbacks in water exports. Meanwhile, two main proposals have surfaced for dealing with levee

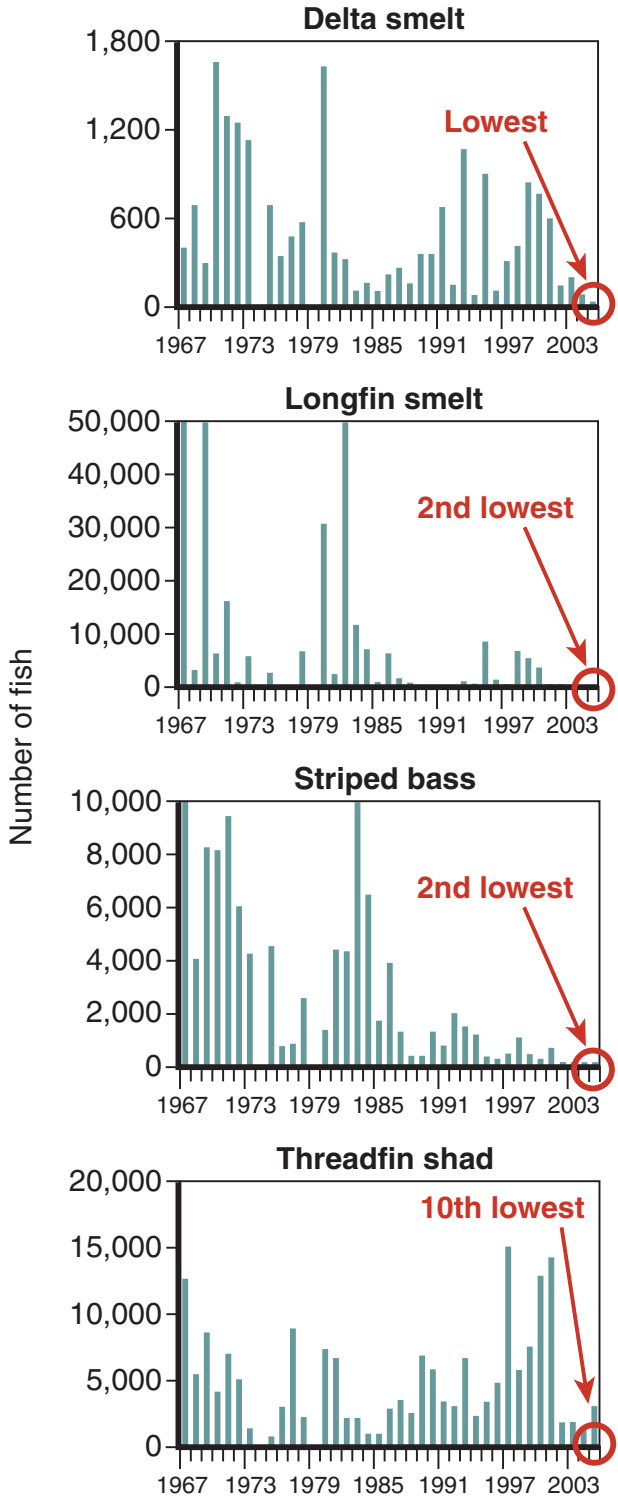
Delta smelt
1,800
1,200
600
0
Lowest
1967 1973 1979 1985 1991 1997 2003
Longfin smelt
50,000
40,000
30,000
20,000
10,000
0
2nd lowest
1967 1973 1979 1985 1991 1997 2003
Striped bass
10,000
8,000
6,000
4,000
2,000
0
2nd lowest
1967 1973 1979 1985 1991 1997 2003
Threadfin shad
20,000
15,000
10,000
5,000
0
10th lowest
1967 1973 1979 1985 1991 1997 2003
Number of fish

FIGURE 1.2

instability: (1) Make massive investments in the levee system to reduce the risk of failure or (2) construct a peripheral canal around the Delta's eastern or western edge, to protect water exports from what many now view as unacceptable risks associated with direct Delta exports. The resurgence of a peripheral canal proposal is significant, because it is a solution that has deeply divided Californians in the past. Strong majorities of Northern California and San Joaquin Valley voters who were concerned over the canal's environmental effects, its potential to export too much water south, and the proposed allocation of costs, succeeded in defeating a peripheral canal proposal in a statewide referendum in 1982. When the CALFED process was launched in the mid-1990s to find new solutions to the Delta's ecosystem and water supply issues, feelings were still so raw that the peripheral canal was not considered an acceptable option.

These proposals have largely emerged from stakeholder groups, and none provides fully fleshed-out plans to address the Delta's woes. To date, the only concrete response from Sacramento, supported by both the governor and the legislature, has been to put more state funds into shoring up Delta levees, which were relatively neglected under CALFED.[3] State budget allocations for levee repairs were increased significantly in 2006, and two bond measures passed in the November 2006 ballot allocate additional funds for flood control in the Delta. However, there is as yet only the beginning of a broad plan for responding to the crisis in the Delta (Natural Resources Agency 2009).

The task at hand is urgent, and the stakes in the Delta are high. If California fails to develop a viable solution and act soon, the risk is loss of native species and significant disruptions of economic activity. Yet there is also a risk that the political process will choose expedient, incremental solutions that preclude or defer essential strategic decisions or prematurely close off the consideration of options that could help California make the most of the Delta, while protecting its unique ecosystem and species.

FIGURE 1.2 Fall abundance indices for several pelagic fish species in the Delta, 1967–2005. Graphs report the indices for the fall midwater trawl. Circles indicate the rank of indices in 2005. For delta smelt, longfin smelt, and striped bass, the recent indices represent low points in long-term declines of their populations. Source: California Department of Fish and Game.

FOUR CENTRAL ISSUES

Long-term solutions for the Delta will need to consider a wider range of issues than simply which levees to upgrade. To be viable, Delta solutions will need to address four central issues: the salinity and quality of Delta waters, in-Delta land use and water supply, water supply exports, and the Delta ecosystem.

DELTA SALINITY AND WATER QUALITY

With rivers feeding into it and marine bays at its western edge, the Delta is the meeting point for seawater and fresh water within the wider estuary system (Knowles 2002). Delta salinity has been a major concern since the city of Antioch's 1920 lawsuit against irrigators in the Sacramento Valley, whose upstream water withdrawals reduced freshwater flows into the Delta and increased the salinity at water intakes in the western Delta (Jackson and Paterson 1977). Salinity affects the potability and taste of urban water supplies, the productivity of farmland, and the viability of different organisms within aquatic ecosystems. For many decades, this issue was discussed in terms of where the salinity gradient—that is, the transition from fresh water to seawater—should be located in the estuary. Since the 1920s, it has been regarded as desirable to maintain the Delta, as much as possible, as a freshwater system, Suisun Bay and Marsh as brackish water systems, and San Francisco Bay as a marine (saltwater) system. The current regulatory framework for water quality in the Delta rests on this idea. More recent thinking, discussed in Chapter 6 and Moyle and Bennett (2008), holds that seasonal and interannual variability in much of the estuary may better mimic the natural salinity regime and help limit the extent of invasive species, which tend to prefer waters with little salinity fluctuation. Increasingly, it has been recognized that salinity and other, broader water quality problems in the Delta are compounded by the quality of upstream and in-Delta drainage, with consequences both for urban and agricultural users as well as for fish and wildlife.

DELTA LAND USE

Land is a central issue for the Delta. Of the Delta's 738,000 acres, roughly two-thirds support agriculture and one-tenth urbanized populations. Although the human population within the heart of the Delta is minimal—limited principally to homesteads and a handful of small "legacy"

towns—larger cities such as Stockton, Antioch, and West Sacramento have long existed on its fringes. The Delta is often thought of as a site of high-value fruit and vegetable farms, but roughly 75 percent of the farmland is actually devoted to lower-value pasture and field crops; in comparison, only 55 percent of farmland statewide is devoted to these uses (Department of Water Resources 1998). And in recent years, urbanization and recreational use of Delta lands have been on the rise.

Various environmental uses of Delta land already exist, including wetlands, riparian habitat, waterfowl uses, and aquatic habitats. Open water—which results when islands are flooded and submerged—also has environmental use, as well as considerable value for recreation, boating, and shipping. Freshwater storage is another recent suggestion for Delta lands. This freshwater storage plan proposes investing in strengthening internal levees on some Delta islands that have subsided below sea level, allowing them to be filled with water, on a tidal or seasonal time scale, to aid water projects in pumping fresh water from the Delta.

Each of these land uses has different implications for water use, the quality of water required in adjacent channels, drainage quality and quantity, and economic sustainability. Fortunately, the Delta is large and diverse enough to support a mix of land uses and habitats.

WATER EXPORTS

Water exports from the Delta are a major cause of controversy. For water users in the Bay Area, Southern California, and the San Joaquin Valley, the reliability and quality of these water supplies are of paramount concern. Yet there are also concerns that export patterns and volumes harm species' health and water quality within the Delta. Many approaches exist for either providing or avoiding this function for the Delta, and numerous options have been proposed over the past century. Even without providing water exports, however, the Delta would still have many serious problems with flooding, land subsidence, degraded habitat, invasive species, and water quality.

DELTA ECOSYSTEM

Different parts of the Delta provide habitat for different wild species and their diverse life stages. The mix of salt, brackish, and freshwater marshes as well as upland, riverine, and deepwater habitats affects the abundance

and distribution of native and alien species. Therefore, anything that changes the physical Delta changes the biological Delta. Since the 1970s, considerable attention has been paid to the effect of water supply functions on ecosystem functions in the Delta. Initially, this discussion focused primarily on the role of water export pumps at the Delta's southern edge, and on efforts to avoid fish entrainment (the drawing and trapping of fish into the pumps). It is now recognized that the same issues of entrainment of fish and invertebrates apply to power plant cooling water and agricultural and urban diversions elsewhere in the Delta. Concerns have also been raised that the total volume and timing of diversions are causing problems for key Delta species by changing the way water flows through the Delta. Given the range of federal and state environmental laws protecting these species, these concerns are legal and political as much as ecological (National Marine Fisheries Service 2008).

SEARCHING FOR A SOFT LANDING

In this book, we look for long-term solutions to these chronic, dire, and potentially catastrophic problems. Rather than focus on crisis management, we consider long-term strategies, under which Californians can develop and implement a plan to adjust to the Delta of the future. This approach, which we refer to as planning for a "soft landing," differs greatly from how California may need to manage short-term crises in the Delta, or what might be considered a "hard landing." If the state is unfortunate enough to experience a multi-levee failure before implementing a long-term plan, effective emergency response will be needed to minimize the costs in terms of water supply and damages to other economic infrastructure.

In assessing long-term solutions, we consider the physical factors that will force a major transition on the Delta, including climate change, sea-level rise, earthquakes, and changing flood flows. We unite perspectives from a wide range of disciplines that are important to Delta analysis—engineering, biology, geology, and economics. We focus on two central questions for long-term Delta policy. First, which Delta islands should be repaired when they fail? We consider the economic sustainability of investment strategies in Delta levees, given the risks of failure, the value of land and other assets, and the costs of protecting Delta lands. Second, what is the preferable long-term water management strategy from a statewide

perspective: continued through-Delta export pumping, a peripheral canal, a dual conveyance system combining through-Delta pumping and a peripheral canal, or ending exports altogether? We compare futures for the ecosystem and California's economy under these four broad water export alternatives, which span the full range of potential strategies. Our aim is to advance policy and public discussions about Delta futures. These broad alternatives present choices that must be made *before* addressing the many decisions required to implement any chosen strategy.

Quantitative risk analysis is the central framework used to evaluate performance, integrating estimates of costs and probabilities with major uncertainties in the performance of each alternative. This framework is particularly useful for assessing policy alternatives in the Delta, given the risks and uncertainties for ecosystem outcomes as well as changing physical conditions in the Delta. To conduct such a risk analysis required detailed analysis of levee risks and economics, hydrodynamics and water quality under future conditions of climate change, analysis of ecosystem response to changes in the Delta, and economic analysis of how California's water supply system could respond to major changes in Delta water export policies. Along the way, we also seek to provide insights into implementation and the governance, finance, and regulatory changes needed to improve the prospects of the Delta from environmental and statewide economic perspectives. Greater detail on many of these topics is provided in a series of appendices to Lund et al. (2008a). All cost estimates are presented in 2008 dollars.

Our analysis does not provide perfect clarity, but perfect clarity should not be needed to select a strategy to solve an urgent problem. We come to firmer and better substantiated conclusions than we expected regarding both Delta island repair and strategic directions for Delta water exports. These findings provide building blocks for a promising new approach to managing this unique and challenged resource, as Californians struggle to preserve the many ecological, economic, and cultural functions of the Delta in the face of inevitable changes.

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