

# COMPARING FUTURES

## FOR THE SACRAMENTO–SAN JOAQUIN DELTA

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# Summary

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“Once a landscape has been established, its origins are repressed from memory. It takes on the appearance of an ‘object’ which has been there, outside us, from the start.”

*Karatani Kojin (1993), Origins of Japanese Literature*

The Sacramento–San Joaquin Delta is the hub of California’s water supply system and the home of numerous native fish species, five of which already are listed as threatened or endangered. The recent rapid decline of populations of many of these fish species has been followed by court rulings restricting water exports from the Delta, focusing public and political attention on one of California’s most important and iconic water controversies.

In our previous report, *Envisioning Futures for the Sacramento–San Joaquin Delta*, we explored the alternatives available for the long-term management of this multifaceted resource. We concluded that change is inevitable for the Delta and that retaining the current policy of exporting large amounts of water through pumps in the southern Delta was both risky and unsustainable. We examined nine long-term strategies for managing the Delta from the perspectives of environmental, economic, and water supply performance.

In this report, we continue the theme of analyzing how the Delta will change in the future and how California can respond to expected changes to meet state economic and environmental objectives. We focus on a central question for long-term Delta policy: Which water management strategies best meet the goals of environmental sustainability and water supply reliability? Many other decisions concerning California’s water management, the Delta aquatic environment, and Delta land use depend on the answer to this question. We provide an integrated analysis of these issues in a series of technical appendices and summarize the results and their policy implications in this report. These analyses allow us to arrive at some firm conclusions regarding the desirability of various long-term alternatives for the Delta from a scientific and technical perspective.

## Managing the Inevitable

Although the Delta is the focus of growing controversies regarding fish and water supplies, it is also being subjected to major physical forces that are at odds with current Delta policy. These physical forces are sea level rise, land subsidence, changing runoff patterns, and earthquakes.

The Delta is a product of sea level rise over the last 12,000 years. At the end of the last Ice Age, the current Delta was only a confluence of rivers flowing to a delta outside the area where the Golden Gate Bridge is now located. As the sea level rose, the Delta began to form as higher tides began to flood the area of confluence about 6,000 years ago. Continuing sea level rise can be seen in the last century of tidal records worldwide and for San Francisco. With climate warming, sea levels and Delta water levels are expected to increase by one to three feet, perhaps more, over the coming century. Without large investments to raise Delta levees, this rise in sea level will cause many levees to fail, pushing seawater into the Delta. Even if the levees could be sustained, sea level rise will increase the salinity of Delta waters.

Land subsidence—or the sinking of Delta islands—began when the marshlands were first diked and drained in the late 1800s, and it continues today as the peat soils oxidize and erode. Most islands are below sea level, many by more than 20 feet. Subsidence increases seepage into the islands, raises the likelihood of levee failures, and increases the costs and consequences of catastrophic island flooding.

California's runoff patterns are changing. Over the last 50 years, there has been a shift toward less snow and more rain in the Sierra Nevada mountains. These shifts—probably associated with climate warming—have increased winter inflows to the Delta. Climate models indicate that this trend will continue, with even larger and more frequent floods in the future. The increases in winter flood flows also will increase island flooding.

Earthquakes are probably the greatest unavoidable threat to today's Delta. Several authoritative investigators have concluded that a major earthquake, such as the 1906 San Francisco earthquake, will likely cause the failure of many Delta islands simultaneously, with a two-in-three chance of such an earthquake occurring within the next 30 years. Such

failures would directly threaten water supplies and would affect thousands of roads, bridges, homes, and businesses at the same time. The water supply costs of such an event are estimated to be in the tens of billions of dollars. The likelihood and costs of earthquake-related failures increase significantly with sea level rise and land subsidence.

The Delta also faces a powerful biological driver of change—the invasion of aquatic and terrestrial species from all over the world. Today, nonnative species dominate the Delta, threatening the survival of remaining native species, changing the way the ecosystem functions, and making the ecosystem and the services it provides less predictable. Unfortunately, new species continue to arrive at a high rate, adding a new wild card to the management deck every time one becomes established.

These factors alone are sufficient to conclude that the Delta of the future will be very different from the Delta of today and the Delta of the past, regardless of what management and policy actions are taken and what happens to California’s environment and economy. Californians cannot go back to the Delta that existed before its marshy tracts were diked and drained; it would require 3.4 billion cubic yards of material to fill subsided islands alone. Nor is it possible to return to the agricultural Delta of the early 20th century; the levee upgrade costs are too great, and salinity will intrude farther into Delta waters even with higher levees. This salinity will decrease the productivity of millions of acres of farmland that depend on Delta waters and will raise water treatment costs and public health risks for the two-thirds of Californians who rely on the Delta as a source of drinking water. Salinity intrusion can be delayed for a time by releasing more fresh water into the Delta, but it cannot be delayed indefinitely. As these changes transform Delta water and landscapes, invasive species will continue to alter the Delta ecosystem.

Even if California could sustain the current Delta against these forces, would it be in the best interests of the state’s residents and environment to do so? As found in our earlier report and confirmed by recent events, the current Delta is performing poorly from almost everyone’s perspective. Given the potential for catastrophic failure of the system, it is important to examine strategic alternatives for managing the Delta. Although the Delta problem is extremely complex, it is unrealistic to seek solutions to all issues

simultaneously. California needs to develop a strategic direction for the Delta before working out all the details of how to get there.

## **Water Exports: A Central Issue in the Delta**

This report focuses on a central question for Delta policy: how to manage Delta water supplies and, in particular, water exports. This question lies at the heart of the wider debates over meeting environmental and economic goals for the Delta. Export policy decisions will drive environmental actions and regulations, determine investments in Delta levees and the ecosystem, and ultimately shape much Delta land use.

In broad terms, there are only four long-term strategies for managing Delta water exports: (1) continue pumping exports through the Delta (the current policy), (2) divert water upstream and convey it around the Delta through a peripheral canal, (3) combine the current through-Delta pumping strategy with a peripheral canal (so-called “dual conveyance” or “dual facility”), and (4) end exports altogether. All Delta water export policies, including those examined in our earlier report, are variants of these four basic strategies. The use of most other tools available to California’s water managers to meet water supply needs—including conservation, groundwater and surface storage, transfers, recycling, and desalination—depends significantly on this strategic decision.

A wide range of environmental management tools could improve conditions for the Delta’s threatened aquatic life. Reducing or ending the use of the southern Delta pumps could prevent fish entrainment and the altered water flows that harm fish. Increasing the volume of water flowing into the Delta and rebuilding variability in Delta water flows are two strategies for creating a more diverse and beneficial aquatic habitat. Ample opportunities also exist to expand aquatic habitat on the Delta’s fringes and within the Delta itself, particularly given the likelihood of island flooding. Methods also are available to improve the design and management of aquatic habitat and to suppress harmful invasive species. The suitability of these tools, and their potential performance, will be significantly affected by the water export strategy employed.

Likewise, many land use, road, rail and other infrastructure decisions in the Delta will largely depend on the state’s long-term strategy for Delta water exports. The present strategy of responding to emergencies only

as they happen puts California in the position of making Delta policy by default rather than by deliberate consideration of the best long-term alternatives.

## Evaluating Strategic Decisions

Because the strategic decision of how to manage water exports is of central importance for so many other management decisions, we focus our analysis on the quantitative comparison and evaluation of the four approaches to exporting water from the Delta. Decisionmaking for other related issues seems likely to become easier once the log-jammed decision on a sustainable long-term Delta export policy is established.

The four alternatives are examined in terms of the two co-equal objectives for the Delta suggested by the governor's Delta Vision Blue Ribbon Task Force: environmental sustainability and water supply reliability. To represent environmental sustainability, we focus on the likelihood of sustaining viable populations of desirable fish species, including native species and others that do well under similar conditions. We assess water supply performance in terms of statewide economic costs and benefits.

To facilitate explicit comparisons among export alternatives, we employ a method known as "decision analysis." This method allows us to explicitly consider a range of possible outcomes, account for major risks and uncertainties, and examine how the water and environmental management system would likely respond to major failures in these alternatives.

For the economic analysis, many aspects of the water export decision can be quantified, making it possible to draw clear comparisons among alternatives. Elements used in the assessment include capital and operating costs, the costs of water shortages, the costs resulting from an extensive Delta levee failure, and the costs of repair after an extensive failure. We also compare alternatives in terms of water quality costs for drinking water treatment and agricultural production. We estimate ranges of answers to reflect the uncertainty in these costs.

The viability of fish populations under different water management alternatives is more difficult to assess. However, California is fortunate to have many experts on the Delta ecosystem and its fishes, and years of studies have improved understanding of these issues. We surveyed a

group of experts on the Delta ecosystem to help us understand how each export alternative would likely affect the viability of fish populations. We complemented these results with an analysis of conditions under which different groups of fish species thrive and our own assessment of how Delta fish species would likely be affected by long-term changes in Delta conditions. This allowed us to establish ranges for the likelihood that fish populations would be sustained for each of the four water export alternatives.

In comparing alternatives, we also consider major risks. For example, if a peripheral canal were built and listed fish species did not recover, legal and political actions would be likely to seek reductions in water exports through the canal. Another uncertainty is the timing of an earthquake or flood that will cause an extensive failure of levees in the Delta, disrupting exports that pass through the Delta.

## Comparing the Water Export Alternatives

When this information on costs, risks, and likely performance of Delta fish populations is integrated in the decision analysis, it produces estimates of the likely ranges of economic costs and fish population viability for each of the four export management alternatives. A summary of our analysis appears in Table S.1 and Figure S.1. Fish population viability estimates are presented for two key Delta species—delta smelt and fall-run Chinook salmon. For delta smelt, viability is defined as achieving sufficient recovery to avoid Endangered Species Act restrictions on water exports. For fall-run Chinook salmon, viability is defined as maintaining adequate populations to support commercial and recreational fisheries.

For some alternatives, the range of likely economic performance is quite broad. A dual facility has likely costs as low as \$250 million and as high as \$1.25 billion per year. For continued through-Delta pumping, the range is even larger, with a low of \$550 million and a high of nearly \$1.9 billion per year. These ranges reflect considerable uncertainty. For through-Delta pumping, a major uncertainty is how soon the system will be damaged by a large-scale levee failure. A dual facility would become much more expensive if extensive investments were made to maintain the through-Delta export channels. For fish, the ranges reflect the considerable uncertainties about species performance, depending in part

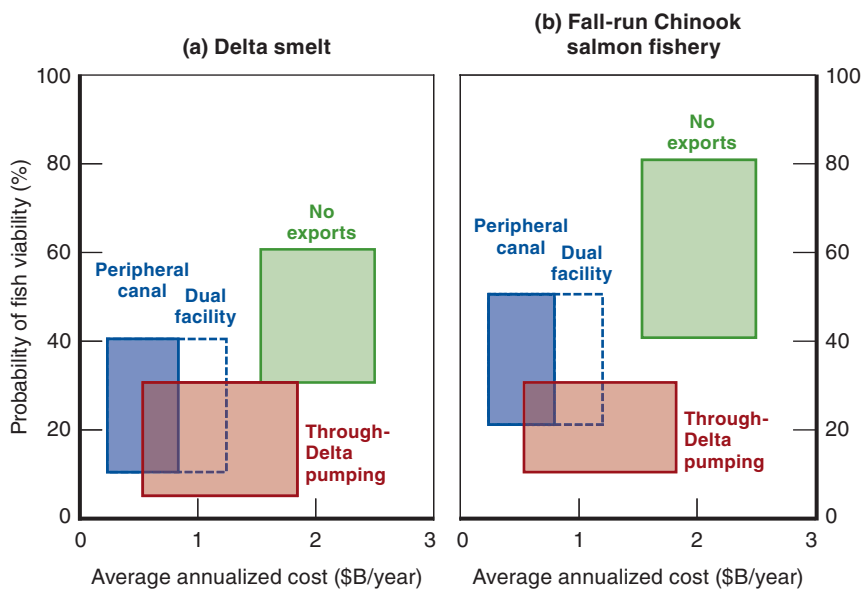


Table S.1

Annual Costs and Likelihood of Fish Population Viability Under Delta Export Alternatives, 2050

Alternative	Average Cost (\$ billion/year)	Likelihood of Viable Populations (%)	
		Delta Smelt Population	Fall-Run Chinook Salmon Fishery
Continuing through-Delta exports	0.55–1.86	5–30	10–30
Peripheral canal	0.25–0.85	10–40	20–50
Dual conveyance	0.25–1.25	10–40	20–50
No exports	1.50–2.50	30–60	40–80

SOURCE: Appendix J.



SOURCE: Appendix J.

Figure S.1—Range of Costs and Fish Population Viability for Delta Export Alternatives in 2050

on how carefully the ecosystem components of any Delta alternative are managed, as well as on influences from external sources (i.e., for salmon, the ocean and upper watershed).

Despite these uncertainties, some clear comparisons emerge. In terms of statewide economic cost, the most likely ordering of alternatives is a peripheral canal (best), followed by dual conveyance, continued through-Delta exports, and, in last place, ending exports. Even if a peripheral canal faced relatively high construction costs (on the order of \$10 billion) and could export only 60 percent of current levels because of endangered species restrictions, its total costs would not exceed \$1 billion per year. Dual conveyance is potentially more costly than a canal alone, because it will likely entail additional infrastructure costs to continue through-Delta pumping. Dual conveyance costs also could be somewhat higher because the lower water quality pumped from the Delta increases costs for urban and agricultural users.

Several key drivers make continued through-Delta pumping relatively costly. First, by mid-century, the increased salinity of Delta waters imposes water treatment costs on the order of \$300 million to \$1 billion per year, every year. Second, this alternative requires significant investments, initially to fortify key levees and to improve Delta channels and, ultimately, to build a peripheral canal when the levee system fails.<sup>1</sup> Third, a catastrophic failure of key levees would cause large one-time costs of \$8 billion to \$15 billion. The no exports alternative, in contrast, involves considerable costs outside the Delta itself, as water users develop alternative, higher-cost sources and reduce water use, particularly for agriculture in the southern Central Valley. Our estimates assume that water users have time to prepare for an end of exports. The costs would be considerably higher—more like those of a catastrophic failure—if they had no time to prepare.

The most likely ranking of alternatives is quite different for fish viability, with no exports being the best, followed by a peripheral canal and dual conveyance (tied), and continued through-Delta pumping in last place. A broad consensus exists among estuarine experts that ending

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<sup>1</sup> Our analysis finds that a peripheral canal would be built after massive levee failure, because this would be the least expensive response. If, instead, a decision were made to rebuild the failed levees or to end exports, the expected cost of the through-Delta strategy would be higher than the range presented here.

exports is likely to be best for a range of desirable fish species—ending the harmful entrainment and unnatural flow patterns generated by the southern Delta pumps, as well as providing more water for aquatic habitat. A peripheral canal provides the first two of these benefits; our estimates of fish viability assume that a peripheral canal would be designed and operated to minimize new entrainment problems at the upstream intake. Although in principle dual conveyance offers some additional flexibility for water management, we do not believe that it will have appreciably different outcomes from a canal-only alternative for either delta smelt or salmon. Finally, continued through-Delta pumping is the least beneficial for fish, given the problems of entrainment and disruption created by the southern Delta pumps. Through-Delta pumping also prevents the more flexible management of environmental water flows to increase aquatic habitat variability.

How do the alternatives compare when environmental benefit and economic performance are considered together, as co-equal objectives?

- The peripheral canal and dual conveyance alternatives are very likely to perform better than continued through-Delta export pumping on both objectives. The peripheral canal has a two-thirds chance of outperforming through-Delta pumping; the chance is 60 percent with a dual facility. In contrast, through-Delta pumping has only a 5 percent chance of outperforming the two canal-based alternatives on both co-equal objectives.
- There seems little reason to prefer a dual facility over a peripheral canal. The two alternatives are likely to perform equally from the perspective of desirable fish species, and dual conveyance is likely to be more costly. Nevertheless, for an interim period, it may be valuable to maintain some through-Delta pumping as part of a dual system, to aid water quality for Delta farmers and provide additional flexibility for exports and environmental operations. With time, the through-Delta portion of dual conveyance will probably become less reliable and more expensive as a result of endangered species regulations, sea level rise, and island failures. A dual conveyance alternative with significant investments to support through-Delta

pumping is unlikely to be worth the additional costs, given the water quality and environmental risks of through-Delta pumping.

- A clear tradeoff exists between a peripheral canal and dual conveyance and the alternative of ending exports. A peripheral canal and dual conveyance are better in terms of costs to the economy, but ending exports is better for fish. Selecting between these alternatives will require a value judgment. The tradeoff may be easier to make if some of the economic benefits of a canal-based alternative could be used to support enhanced ecosystem investments in the Delta, thereby improving environmental outcomes.

Selecting an export strategy does not, in itself, solve the Delta's problems; it is only a necessary step toward a solution and should provide a framework that improves subsequent decisionmaking. Many technical, regulatory, financial, governance, and policy decisions must accompany the implementation of a long-term strategy. In particular, no matter which export strategy is selected, there will have to be investment in improvements of aquatic habitats within the Delta to increase the likelihood of fish recovery. As indicated by the range of costs and likelihood of restoring fish populations to health, the implementation details will be at least as important as the specific strategy selected.

## **Policy and Regulatory Implications**

Almost a century of Delta regulations, laws, policies, and agreements have revolved around the historical policy of maintaining the Delta as a largely freshwater body and exporting water through the Delta. This situation no longer serves the interests of the state's environment or economy. An institutional framework is required for establishing, operating, regulating, and financing a new Delta strategy. Successful new institutional arrangements are unlikely to emerge from a stakeholder-led process. Large numbers of parties with divergent interests are ill-suited to crafting workable solutions without outside leadership. The governor and the legislature can provide the necessary leadership to make such profound institutional changes to prepare for and manage the Delta of the future.

# Conclusions

Our conclusions can be summarized in four broad areas.

1. **Fundamental changes are inevitable in the Delta.** “Restoring the Delta” is an unrealistic notion given the historical changes that have occurred and the immutable forces that will affect the Delta in the decades to come.
  - Sea level rise, earthquakes, continued land subsidence, and higher winter flood flows will increase the frequency and costs of Delta island failures.
  - Maintaining all Delta islands is not cost-effective.
  - The Delta of the future—with large bodies of open water—will significantly differ from the Delta of yesterday or today.
  - California is unprepared for the changes that will occur in the Delta.
2. **Conditions for the Delta’s fish can be improved.** Naturally occurring improvements include greater aquatic habitat as islands become permanently flooded. Managed changes in water intakes, water operations, and habitat also can improve conditions for fish but the following issues must be considered:
  - Rebuilding large, self-sustaining populations of desirable Delta fish species will require large and carefully designed ecosystem investments.
  - More diverse habitat is fundamental to improving conditions for desirable fish species, with greater variability in Delta water flow and salinity as part of this strategy.
  - Water export alternatives matter for fish, and the current export alternative is almost certainly the worst for desirable fish species.
  - Preventing new invasions of alien species and better control of existing problem invaders are needed to create a more predictable and favorable environment.
  - Some species in the Delta are likely to be sustained only with heroic efforts.

3. **For water exports, time favors a peripheral canal and is unfavorable to other alternatives.** Figure S.2 presents a conceptual view of how export alternatives are likely to perform over time and the choices California will face. Water exports are currently declining from historical high levels as a result of court rulings regarding endangered species. Additional species listings are likely to cause further export reductions in the near term. The accumulating effects of land subsidence, sea level rise, worsening floods, and earthquakes will make continuation of through-Delta pumping less reliable and more costly over time but it will leave peripheral canal exports relatively unaffected. However, it will take some time before a peripheral canal can be constructed. How well a dual conveyance alternative ultimately performs will depend on the size of the canal component. If the canal were sufficiently large, it could take an increasing share of exports as through-Delta pumping became less viable. As the figure highlights, the ability of each alternative to support fish populations also significantly affects its ability to support exports.

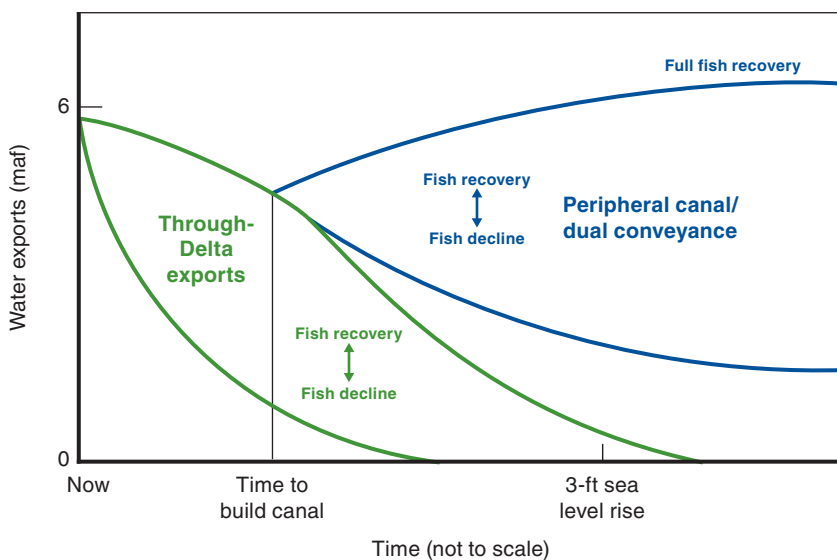


Figure S.2—Delta Export Transitions over Time

4. **A peripheral canal is a necessary component of a long-term solution that serves economic and ecosystem objectives co-equally.**
  - Sea level rise will make Delta export pumping increasingly unattractive and eventually infeasible.
  - The long-term water export choice is between building a peripheral canal (which is best for the economy) and ending Delta exports (which is best for fish).
  - A potential compromise is to allocate some of the savings generated by a peripheral canal to enhanced ecosystem investments.
5. **A successful long-term Delta solution will require governance, regulatory, and finance arrangements that allow decisions to be made in a timely way.**
  - To be viable, a peripheral canal or dual conveyance would require effective governance, regulatory, and financing mechanisms.
  - Governance mechanisms can be devised to provide appropriate environmental safeguards for a peripheral canal.
  - Financing mechanisms are available to cover the range of water system needs.
  - It makes economic and environmental sense to involve upstream diverters, as well as users of exported water, in providing more water to the Delta.
  - Establishing these arrangements requires involvement from the legislature and governor.
  - The current regulatory framework is not prepared to deal with the Delta of the future.

## Recommendations

The Delta of the future will be very different, and the costs of inaction are high. California needs to prepare for this changed future to direct it more favorably. This means charting a new strategic direction for Delta water management, planning environmental investments from the vantage point of a changing Delta, and developing strategies to manage levee failures. Preparing for the future through governance and regulatory reforms is also essential.

**1. Initiate a planned transition away from through-Delta pumping to other export strategies.**

Table S.2 summarizes the role of the four alternatives in the context of such a transition. Continued through-Delta exports are already demonstrably harmful to the environment, and with time they become unviable for the state’s economy. The transition away from through-Delta pumping will occur over time, whether planned for or not. A more expeditious, planned transition would be less susceptible to the rapid, costly changes accompanying earthquakes, floods, and levee failures.

**2. The most promising strategy for meeting co-equal long-term state environmental and economic objectives is a peripheral canal.** This strategy should include the following elements:

- Export water users commit up front to pay for a peripheral canal and water export facilities.
- Safeguards on the operation of a peripheral canal are provided through governance and ownership institutions rather than by limits on the physical capacity of the canal, to enable better environmental and water supply performance
- Export water users and upstream diverters commit funds and water to improve the ecosystem. Although upstream diverters have more senior water rights, both groups of users are partially responsible for declines in the Delta ecosystem.

Table S.2

Summary Comparison of Water Export Alternatives

Alternative	Performance
Continued through-Delta exports	Increasingly unstable and costly solution
Dual conveyance	Interim solution for transition to peripheral canal
Peripheral canal	Potential to provide both cost-effective water supply and improved fish viability
No exports	Best for fish but most costly to the economy; ultimate outcome without a peripheral canal



3. **Actively prepare for a changing Delta ecosystem.** Habitat conservation planning needs to consider the effects of sea level rise, climate warming, permanent levee failures, and new invasive species. A rigidly negotiated habitat conservation plan is unlikely to succeed; experimentation and detailed modeling studies to inform a decision-capable governing framework will be needed.
  - Ecosystem management should favor diverse habitat and flow conditions for multiple species.
  - An experimental ecosystem restoration program should be launched and should include flooding at least one Delta island.
  - Hydrodynamic modeling needs to consider sea level rise, permanently flooded islands, and the potential for managing Delta flow patterns to favor desirable fish species.
4. **Move away from levees as the primary means of managing Delta land and water.** Prepare for island failures. Provide major state levee investments only for those Delta islands that have a cost-effective statewide interest; devise mitigation strategies for land owners on other islands.
5. **Develop a new framework for governance and regulation of the Delta.** In addition to developing workable governance and finance institutions for water supply and ecosystem management, policymakers need to anticipate regulating a very different Delta environment.
  - The regulatory consequences of sea level rise and island failures need to be addressed now, so that flexible water management tools are readily available to help California meet its environmental and economic goals.
  - Options need to be assessed for making long-term habitat conservation planning compatible with changing Delta conditions.
  - The number, importance, and urgency of problems associated with a Delta transition require a decision-capable governance and regulatory system and one that is at least somewhat more centralized than the current, highly decentralized system. The current governance system is effective at tinkering with the status quo but will likely be ineffective in overseeing any sort of major transition.

## Charting the Future for a Changing Delta

The ongoing and increasingly rapid changes in the Delta pose a long-term challenge to California as a whole, as well as to all parties involved in this perennial source of conflict. All parties seeking to achieve the Delta Vision's co-equal objectives of environmental sustainability and water supply reliability have an interest in making a peripheral canal part of a long-term solution for the Delta. This strategy must be embedded in a comprehensive set of actions to improve aquatic environments in the Delta and the greater watersheds of the Sacramento and San Joaquin Rivers. To be viable, a long-term solution must include governance, regulatory, and financial arrangements to ensure that various goals are well served, including water supply, environmental management, and the state's local interests in the Delta. It is unlikely that local and regional stakeholders can negotiate such arrangements on their own in a timely way, given the complexity of the problem and its innumerable stakeholders. Pursuit of a grand consensus solution for the Delta's many issues is likely only to continue the deteriorating status quo. Leadership from the governor and legislature will be needed to create conditions for reasonable governance of the new Delta, with cooperation from local governments and federal agencies that regulate and manage water and land use.

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# Preface and Acknowledgments

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Like our earlier report, *Envisioning Futures for the Sacramento–San Joaquin Delta*, this report is a multidisciplinary collaboration among authors representing a variety of disciplines, including engineering (Jay Lund and William Fleenor), economics (Ellen Hanak and Richard Howitt), biology (Peter Moyle and William Bennett), and geology (Jeffrey Mount). The report represents a consensus among these authors, each of whom brings many years of knowledge and diverse perspectives to the discussion of the Delta.

Our first report provided an orientation to long-term Delta problems and alternatives; this report is more analytical and quantitative in content. We focus on the central water management issue for the Delta: whether and where exports of Delta waters should occur. To better inform ongoing policy processes, we conducted this study within a few months (beginning January 2008). Much has been achieved during this period, but much more remains to be done, especially regarding the important implementation decisions accompanying any policy strategies. We hope that this report serves similar purposes as our earlier report, to help structure the problems and solutions for the Delta and help narrow the range of promising long-term alternatives.

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We alone are responsible for any remaining errors. Research publications reflect the views of the authors and do not necessarily reflect the views of the staff, officers, or Board of Directors of the Public Policy Institute of California.

# Acronyms and Abbreviations

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BDCP	Bay Delta Conservation Plan
CALFED	state and federal program for the San Francisco Bay and Sacramento–San Joaquin Delta
CALVIN	California Value Integrated Network model
CCWD	Contra Costa Water District
cfs	cubic feet per second
Clifton CF	Clifton Court Forebay
CVP	Central Valley Project
DRMS	Delta Risk Management Strategy
DWR	Department of Water Resources
EC	electrical conductivity
ESA	Endangered Species Act
HCP	Habitat Conservation Plan
maf	million acre feet
NCCP	Natural Communities Conservation Plan
PC	peripheral canal
POD	pelagic organism decline
SWP	State Water Project
SWRCB	State Water Resources Control Board
taf	thousand acre feet
WAM	water analysis module
WQCP	Water Quality Control Plan



# Glossary: Words and Phrases

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**Adaptive management**—A flexible, learning-based management approach in which natural systems are managed to ensure their recovery and improvement, while an understanding of how these systems function is developed to raise the effectiveness of future management actions.

**Anadromous fish species**—Fish that live in ocean water and move inland to spawn, such as salmon.

**Consumptive water use**—Divisions of water withdrawn but not returned downstream.

**Desirable fish species**—Fish with at least two of the following attributes: (a) listed as threatened or endangered, or proposed for listing, under state or federal Endangered Species Acts; (b) support an important sport or commercial fishery; (c) endemic or native; and (d) dependent on the estuary to complete their life cycle, either by living there or migrating through it.

**Cumulative probability**—The total probability over a range of values or time periods.

**Electrical conductivity**—A surrogate measurement for salinity in water.

**Environmental water**—Water allocated to support fish and aquatic habitat, often through minimum flow requirements.

**Estuary**—A semi-enclosed embayment where saltwater is significantly diluted by fresh water from inflowing rivers.

**Export diversions**—Water diverted from the Delta watershed for use in areas to the west and south of the Delta.

Export pumps—Pumps used for water exports, primarily in the southern Delta.

Fish entrainment—The drawing of fish or fish larvae into pumps or water diversions.

Ground acceleration—A measure of intensity of shaking during an earthquake, often described as proportional to the acceleration due to gravity.

Hydraulic factors—Water movement's effects on biological and physical processes.

Hydrologic conditions—Conditions related to water inflows.

Hydrodynamic—The physics of water movement and the movement of matter (e.g., sediment, salts) in the water.

Inflows—Natural or managed flows of water into a particular location.

Land subsidence—The sinking of lands caused by compaction, oxidation of peat soils, and wind erosion. Many Delta islands have subsided (mostly from oxidation and erosion) to the point where they now lie many feet below sea level.

Minimum flow requirements—Water flows required by regulators, typically for environmental purposes.

Mitigation—An action intended to moderate some effects of other activities. For instance, flood management agencies often make one-time payments (known as “flood easements”) to property owners in areas that will be allowed to flood periodically to help cover the costs of flooding.

Pelagic fish species—Fish that live their whole life in open water, above the bottom. Within the Delta, this category includes delta smelt, longfin smelt, and striped bass.



PL 84-99 standards—Minimal standards for levee construction in the Delta to qualify for federal assistance in repairs and rehabilitation.

Outflow—Flows of water going away from a particular location.

Salinity—The concentration of salt in water. As a rough guide, seawater is 35 parts per thousand (ppt) (grams per liter) and fresh water is less than 3.0 ppt. Drinking water is less than 1.0 ppt.

Unimpaired flows—Streamflows unaffected by upstream dams, diversions, or return flows.

Upstream diversions—Indirect exports from the Delta watersheds (mainly in the Sacramento Valley and on the east side of the San Joaquin Valley) before the water reaches the Delta.

Water diversions—The withdrawal of water from a water body, some of which might be returned downstream after use.

Water exports—In general, water used somewhere other than its area of origin. Direct Delta exports refers to water from Delta watersheds that is sent to points south and west of the Delta. Upstream diversions are a form of indirect exports.

Water scarcity—Occurs when water deliveries are less than desired. Scarcity is often managed by price, rationing urban water use, fallowing some farmland, or curtailing recreational activities.

Water transfers—The exchange, leasing, or permanent sale of the rights to use a particular amount of water from a particular source. Such transfers occur through a “water market,” usually involving local and regional water agencies and often state and federal agencies.

Water year—California’s water year begins on October 1st, the beginning of the rainy season, and ends on September 30th.



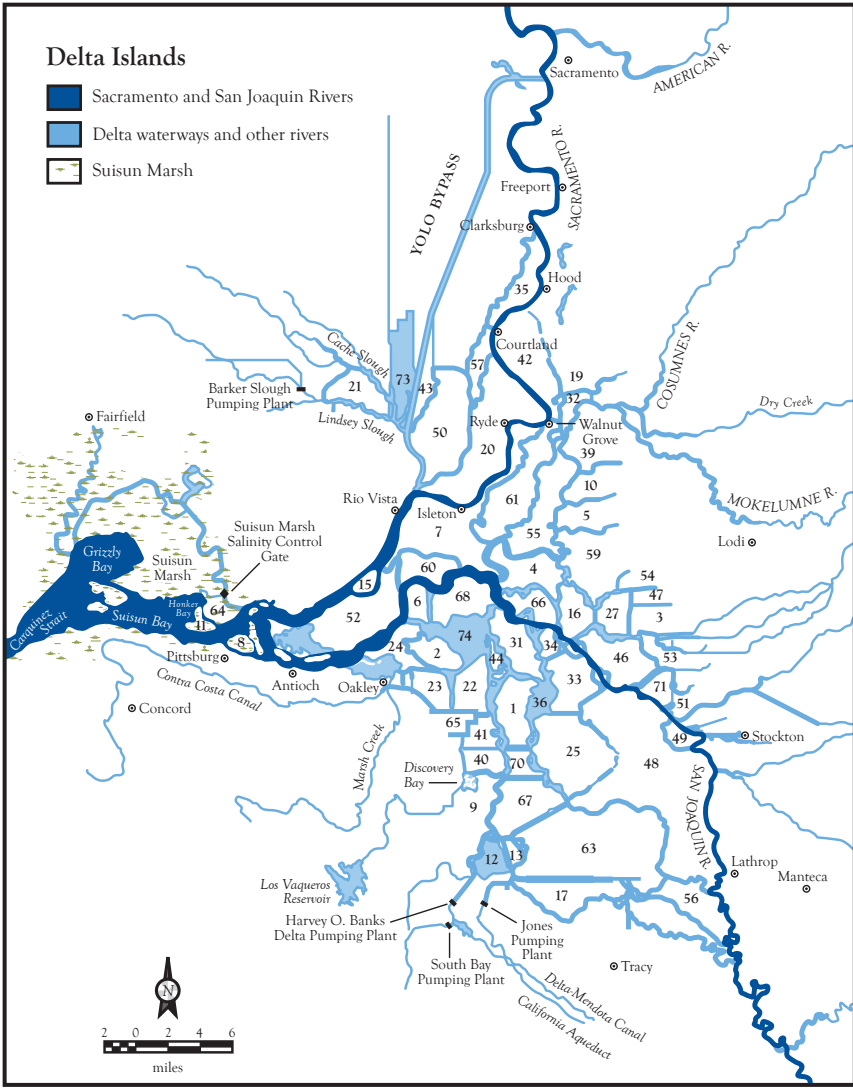


Figure S.3—Delta Islands Map

### Legend for Delta Islands in Figure S.3

Bacon Island	1	Netherlands	37*
Bethel Tract	2	Neville Island	38*
Bishop Tract	3	New Hope Tract	39
Bouldin Island	4	Orwood Tract	40
Brack Tract	5	Palm Tract	41
Bradford Island	6	Pierson District	42
Brannan-Andrus Island	7	Prospect Island	43
Browns Island	8	Quimby Island	44
Byron Tract	9	Rhode Island	45*
Canal Ranch	10	Rindge Tract	46
Chipps Island	11	Rio Blanco Tract	47
Clifton Court Forebay	12	Roberts Island	48
Coney Island	13	Rough and Ready Island	49
Deadhorse Island	14*	Ryer Island	50
Decker Island	15	Sargent Barnhart Tract	51
Empire Tract	16	Sherman Island	52
Fabian Tract	17	Shima Tract	53
Fay Island	18*	Shin Kee Tract	54
Glanville Tract	19	Staten Island	55
Grand Island	20	Stewart Tract	56
Hastings Tract	21	Sutter Island	57
Holland Tract	22	Sycamore Island	58*
Hotchkiss Tract	23	Terminus Tract	59
Jersey Island	24	Twitchell Island	60
Jones Tract	25	Tyler Island	61
Kimball Island	26*	Union Island	63
King Island	27	Van Sickle Island	64
Little Franks Tract	28*	Veale Tract	65
Little Mandeville Island	29*	Venice Island	66
Little Tinsley Island	30*	Victoria Island	67
Mandeville Island	31	Webb Tract	68
McCormack Williamson Tract	32	Winter Island	69*
McDonald Tract	33	Woodward Island	70
Medford Island	34	Wright-Elmwood Tract	71
Merritt Island	35	Liberty Island	73
Mildred Island	36	Franks Tract	74

NOTE: Numbers with asterisks denote islands not shown on map because of space limits.

# 1. 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*

The Sacramento–San Joaquin Delta is the foremost water management problem facing California today. The Delta forms part of the largest estuary on the West Coast, providing a home to roughly 50 species of fish and close to 300 species of birds, mammals, and reptiles. It also serves as the major hub 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. The Delta’s ecological and water supply 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. Because the current water supply system has changed the Delta ecosystem in unfavorable ways, water exports also are susceptible to cutbacks to protect endangered fish species.

## The *Envisioning Futures* Report

In February 2007, we published a report, *Envisioning Futures for the Sacramento–San Joaquin Delta*, with the intent of stimulating a wide-ranging policy discussion about the Delta’s future (Lund et al., 2007). We concluded that the current system for managing the Delta is unsustainable from the perspective of the environment and almost all human users of Delta services. The report explored and compared long-term solutions for the Delta and identified promising alternatives for managing the region in a more environmentally and economically sustainable way. The two types of alternatives we considered most promising included a new conveyance system for water exports, such as a peripheral canal to move water around the Delta, and a more variable “opportunistic” export regime, which would continue to pump water through the Delta but only when it

was not harmful to the ecosystem. We also suggested new approaches to Delta governance and finance and proposed mitigating the harm to those affected by changes in Delta management. Finally, we noted the failure of stakeholder consensus processes for developing realistic and promising alternatives from a statewide perspective.

## **New Initiatives and New Troubles in the Delta**

Since *Envisioning Futures* was released, several policy initiatives have been under way to develop sustainable solutions to Delta problems. The governor's "Delta Vision" initiative, led by an independent Blue Ribbon Task Force, released its strategic vision at the end of 2007 (Isenberg et al., 2008). The task force will develop a strategic long-term plan by October 2008. Separately, water exporting agencies, fisheries agencies, and many environmental and local interest groups are working to develop a Bay Delta Conservation Plan (BDCP)—a habitat conservation plan for improving the management of protected aquatic species that will regulate Delta exports—within a similar time frame. Meanwhile, the legislature has been exploring options for improving Delta ecosystem and water management through a special session on water, several initiatives and water bond discussions, and Senate Bill 27 (Simitian).

Each of these efforts has highlighted the importance of balancing water supply and ecosystem needs—two objectives that the Blue Ribbon Task Force labeled "co-equal" goals for Delta management. Each effort is exploring the possibility of building a peripheral canal, most likely to be managed as a "dual" conveyance system with some continued Delta export pumping. To support the decision process regarding Delta conveyance, the governor's office recently instructed the Department of Water Resources to analyze these and other alternatives as part of an environmental impact review.

The sense of urgency has been heightened by deteriorating conditions for key Delta fish species. Since December 2007, the export pumps in the southern Delta have been operating at reduced levels under an order from federal Judge Oliver Wanger because the Central Valley Project and the State Water Project were found to be in violation of the federal Endangered Species Act regarding delta smelt. Spring 2007 population counts for this species, which have been in sharp decline since 2004, registered another

precipitous drop, raising fears that the smelt are bordering on extinction. Export users estimate that the new rules, in place until a more viable long-term solution is found, will reduce water exports by roughly 22 to 30 percent (Department of Water Resources, 2007b). Further cutbacks may be ordered as the result of a second decision by Judge Wanger (April 2008) to protect the listed winter- and spring-run Chinook salmon, both in decline.

Other key species also are in trouble. After fall 2007 surveys recorded the lowest numbers on record for longfin smelt, another pelagic (open-water) species that lives in the Delta, this fish was listed as a “candidate species” under the California Endangered Species Act in February 2008. This action likely implies additional regulations at the pumps. Since 2006, there has also been a rapid decline of fall-run Chinook salmon, forcing closure of the ocean commercial and sport fisheries in California and most of Oregon for 2008.

## **The *Comparing Futures* Study**

In the deliberations over long-term alternatives for the Delta, several critical issues have yet to be analyzed in depth: How will changes in water management affect the Delta ecosystem as well as the quantity and quality of water available for human use? How will climate change alter these outcomes? How would the regulatory system need to adapt to accommodate different alternatives? How can California make strategic decisions about the Delta given the uncertainties about ecosystem and climate effects?

The goal of this study is to provide substantive answers to these questions. As before, we unite perspectives from a wide range of disciplines that are important to Delta analysis—engineering, biology, geology, and economics. We focus on the most central strategic decision about Delta water management—whether to continue with through-Delta export pumping, to build a peripheral canal, to operate these two options in combination as a dual conveyance system, or to end exports altogether. All Delta export alternatives are some variant of one of these strategies. We compare futures for the ecosystem and California’s economy under these four broad alternatives. Our aim, as before, is to advance policy discussions

about Delta futures. These four alternatives present choices that must be made before many substantial implementation decisions.

We provide an integrated analysis of many of the factors and uncertainties that affect the environmental and economic performance of these four water export strategies. 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. 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 policies needed to improve the prospects of the Delta from environmental and statewide economic perspectives. Each of these topics is summarized in this report, with greater detail provided in a series of appendices.

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 strategic directions for Delta water exports. To be effective, this direction will need to be accompanied by a suitable governance and finance package to ensure reasonable implementation.

We begin our analysis of these four approaches to water exports with a discussion and analysis in Chapter 2 of the long-term physical drivers of change in the Delta—sea level rise, continued land subsidence, changes in runoff patterns, and seismic risks. We assess the sustainability of the Delta levees, which are the backbone of the current water supply system. Chapter 2 also provides an economic framework for assessing which levees are worth upgrading or repairing and a first cut at creating a list of islands where failure repair costs exceed economic benefits. Chapter 3 provides an overview of the four fundamental approaches to water exports available to California to respond to the external changes and sustainability problems of the current levee-centered Delta policies. Chapter 4 draws on new hydrodynamic modeling results to assess the effects of sea level rise and additional flooded islands on the salinity of Delta waters. Chapter 5 considers the implications of these changes in water quality, invasive



species, and other factors on the Delta's ecosystem and key fish species. In Chapter 6, we use a set of economic and engineering models to explore the water supply and water quality costs for urban and agricultural water users under the four water export alternatives and related Delta water management policies. Chapter 7 explores some key regulatory and governance issues that will arise from direct human actions, such as the construction of a peripheral canal, as well as from external forces, notably sea level rise.

Chapter 8 integrates results from the foregoing analyses to compare the merits of the alternatives from the joint perspectives of ecosystem and economic performance. It provides a decision analysis framework and calculations for considering the key uncertainties inherent in any decision about Delta water management: the effects of sea level rise, the risks of levee failure, the viability of Delta fish species, the economic and financial costs of construction of new facilities, and the regulatory risks of water export curtailment if Delta species do not fare well. Chapter 9 synthesizes our main conclusions and outlines our assessment of steps needed to best prepare for the policy choices that lie ahead.

All cost estimates presented in this report are in 2008 dollars. Several online technical appendices provide greater details on many of the results presented here. A brief description of each appendix is provided at the end of this report. Spreadsheets for analysis of island levee decisions (Appendix B) and the comparison of Delta water export strategies (Appendix J) also are available on the web ([http://www.ppic.org/content/pubs/other/708EHR\\_appendix.pdf](http://www.ppic.org/content/pubs/other/708EHR_appendix.pdf)).



## 2. Managing the Inevitable

---

“Assuming no public aid, it is conceivable that the exhausting peat will cause land to subside to the point where drainage and levee maintenance costs will make continued operations impracticable.”

*John Thompson (1957), The Settlement Geography of the Sacramento–San Joaquin Delta, California*

### Introduction

The Sacramento–San Joaquin Delta is significantly changed from its historic condition. Before the arrival of Europeans, the Delta was one of California’s most dynamic landscapes. Lying at the confluence of the Sacramento and San Joaquin Rivers and their floodplains at the head of the San Francisco Estuary, with its extensive marshes and tidal channels, “equilibrium” in the Delta consisted of incessant change adapting and self-adjusting to daily tides, annual floods and droughts, shifts in climate, and rise in sea level. As noted in *Envisioning Futures*, the policies and practices of the past 150 years have overtly or inadvertently reduced the Delta’s dynamic character. Reclamation of marshes and floodplains through construction and maintenance of 1,100 miles of levees sought to freeze the landscape in place, ending the historic connection between landscape-shaping water flows and the landscape itself. For decades, the Delta’s waters and lands have been managed in this artificial way, by fixing levees each time they fail and changing releases from upstream reservoirs and the timing of water exports to keep the Delta’s waters fresh.

Natural systems that have been heavily influenced by human activities—of which the Delta is a prime example—are vulnerable to significant change from two distinct sources (Berkes and Folke, 1998). First, external factors (such as climate change) can dramatically alter conditions. Second, the way human activities interact with natural processes can create additional pressures. As these systems lose their resiliency, they become vulnerable to dramatic and potentially abrupt shifts in physical and biological conditions (Liu et al., 2007). These changes are often associated with thresholds or tipping points where change is both

fundamental and irreversible, defining a new regime or state (Gunderson and Holling, 2001).

The Delta is at a tipping point. The transition between the tidal freshwater marsh of the early 19<sup>th</sup> century to the subsided island–tidal channel network of the 20<sup>th</sup> century was a dramatic and rapid change for this region. Today’s Delta is unstable and poised for another major change. Subsidence, sea level rise, changing inflows, and earthquakes, along with the escalating costs of resisting these processes, are shifting the Delta toward a markedly different state from that of the 19<sup>th</sup> and 20<sup>th</sup> centuries. As outlined below and in Appendix B, these physical and economic drivers of change will transition the Delta during this century to a system with significant amounts of open water as islands flood permanently. This shift in conditions, and the uncertain responses of the Delta’s many aquatic and terrestrial species, poses an unprecedented management and policy challenge for California.

## Drivers of Change

Failure of levees and associated island flooding, whether planned or unplanned, will be the most visible manifestation of transformation for the Delta.<sup>1</sup> Levee failures have many causes, including overtopping, through-seepage, under-seepage, slumping, compaction, and foundation failures during earthquakes. The risks of levee failure in the Delta are currently high, and four physical factors will compound these risks over time: subsidence, changing inflows, sea level rise, and earthquakes.

---

<sup>1</sup> 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” in this report 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.

## ***Subsidence***

The most dramatic landscape change in the Delta is subsidence: the lowering of the land surface throughout most of the Delta as a result of the oxidation of organic-rich soils during farming (Deverel, 2007). Subsidence increases the hydraulic forces that cause levee failure and island flooding by increasing the difference in elevation between the island interior and the water surface in adjacent channels. Subsidence also increases the consequences of major levee failures, because it causes more saline water to be pulled into the Delta from the San Francisco Bay, extending the interruption of water supply exports. Subsidence also increases levee repair costs by expanding the size of levee breaches and increasing the amount of water that must be pumped from flooded islands, as well as increasing island drainage pumping costs if levees do not fail. Mount and Twiss (2005) used a simplified model to project subsidence for the next 50 years in the Delta, assuming continued land use patterns. They projected that an additional one billion cubic yards will be lost from the Delta by 2050 from soil oxidation alone. Most subsidence will be in the central, western, and northern Delta where thick, organic-rich soils predominate.

## ***Changing Inflows***

Broad scientific evidence indicates that California's hydrology is changing. A recent synthesis by Barnett et al. (2008) of the hydrology of the western United States confirms a trend noted by several authors in the last decade. Most notably, the mix of rain and snow in mountainous regions has been shifting for much of the past 50 years, leading to more winter runoff, with an earlier spring snowmelt. The intensity of winter floods also has increased during this period, consistent with this shift of runoff to the winter (Stewart et al., 2004). Climate projections for California are in broad agreement that current trends toward earlier runoff will continue.<sup>2</sup>

Recent studies, such as those by Maurer (2007), indicate that this shift in timing also may be accompanied by increases in the interannual variation and magnitude of peak runoff events. As Florsheim and Dettinger (2007) have demonstrated, even with significant improvements

---

<sup>2</sup> For a summary, see Cayan et al. (2008a).

in levees, the frequency of levee failures in the Central Valley, and in the Delta specifically, are tied directly to the frequency of large storms. Thus, the increasing intensity of winter inflows to the Delta may increase the frequency of levee failures.

### ***Sea Level Rise***

The past century has shown a well-documented rise in sea level (Church and White, 2006) that has directly affected the San Francisco Estuary. Sea level is tied to all aspects of the estuary, especially its elevations and tidal hydrodynamics (Atwater et al., 1979; Krone, 1979). The CALFED Independent Science Board has reviewed this issue and has used empirical models to recommend expecting a mid-range value of roughly 28–39 inches in sea level rise by 2100, with approximately one-third of that rise occurring by 2050 (Mount, 2007).

Cayan et al. (2008b) suggest that sea level rise will have several important effects on the Delta. Beyond simply a rise in mean water surface elevations, with associated increases in pressure on levees, sea level rise will increase the frequency and duration of extreme high water events from the co-occurrence of high tidal elevations, El Niño–like disturbances, low pressure systems, and high inflows. This increase in the length of time levees are stressed by high water elevations will significantly raise the likelihood of failures.

### ***Earthquakes***

The Delta's levees are constructed on poor foundations subject to failure during significant earthquakes. The most recently completed review of the risk of levee failure from earthquakes (Torres et al., 2000), which used limited geotechnical information regarding levees and their foundations, showed that ground accelerations from earthquakes with 100-year recurrence intervals (annual probability of 1%) are sufficient to cause multi-island flooding. The failure risk is highest in the western Delta, where levees close to possible earthquake faults are poorly constructed and on weak foundations.

A more comprehensive assessment of Delta earthquake risks is being completed as part of the Department of Water Resources' Delta Risk Management Strategy (DRMS) program. Although in draft form and

undergoing revision, the DRMS assessments to date show exceptionally high probabilities of failure from earthquakes, with indications that ground accelerations from earthquakes with 20-year recurrence intervals (5% annual probability) can generate multi-island failures (URS Corporation and Jack R. Benjamin and Associates, 2007b). This is consistent with estimations of a 62 percent probability of a large earthquake in the Bay Area within the next 30 years (U.S. Geological Survey, n.d.). The probability of a major earthquake occurring in the region also increases with time as stress builds on Bay Area fault systems.

## Managing or Resisting Change

Together, the forces acting on the Delta's levees—subsidence, changing inflows, sea level rise, and earthquakes—are attempting to shift the Delta from its current configuration as a network of levees protecting subsided islands toward an expanse of open water fringed by tidal marsh. The timing, magnitude, and location of change in the Delta will depend in part on society's investments to resist or accommodate these changes, whether through levee improvements or repairs following failure.

Roughly two-thirds of the Delta's 1,100 miles of levees, including most levees in the heart of the Delta, are “nonproject” levees, managed by local reclamation districts on behalf of island landowners. The remaining one-third are “project” levees, included in federally authorized flood control projects under the authority of the U.S. Army Corps of Engineers and the state Department of Water Resources. In recent years, state subventions to support private landowners' costs of annual levee maintenance and repair in the Delta on the nonproject levees have been relatively modest (approximately \$10 million per year)<sup>3</sup> but have improved overall levee performance in the Delta. The state also has stepped in to cover expensive failures of nonproject levees—such as the Jones Tract failure in June 2004, which cost \$90 million to repair.<sup>4</sup> Delta levees also are likely to gain

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<sup>3</sup> For a summary of expenditures in the Delta Levees Subventions Program and the Delta Levees Special Flood Control Projects program, see Department of Water Resources (2007a).

<sup>4</sup> The Middle River levee, which protects the western edge of Jones Tract, failed on June 3, 2004, filling the 12,000-acre island with an average of 12 feet of water.

from half a billion to a billion dollars from two bond measures passed in November 2006.<sup>5</sup>

Even large state investments in levees using the new bond funds are unlikely to significantly alter the trajectory of change in the Delta. To illustrate the magnitude of this problem, we calculated the annual probability of island flooding from floods and earthquakes of 36 subsided islands that make up two-thirds of the Delta (Appendix B). These annual probabilities are based on the latest draft DRMS reports and account only for today's risk, not increasing future risk. Thus, this analysis represents a business-as-usual approach, assuming continued investments in island maintenance and repairs. Although the probability of an island flooding in any single year may be low (for example, less than 5% for a typical Delta island), the *cumulative* probability of an island flooding some time in the next 50 years is much higher. Figure 2.1 plots the likelihood of island failure, based on present risk factors: The further the point in the future, the higher the accumulated likelihood of failure some time during that period. This estimation shows that Delta islands facing the median risk of failure have a 95 percent chance of failure from floods or earthquakes some time in the next 50 years. Half of the islands have a higher probability of failure over this time period, with western islands most at risk, with a 98 percent chance of failure some time before mid-century. Incorporating future increases in risk from subsidence, sea level rise, inflows, and earthquakes would increase this already high probability of failure.

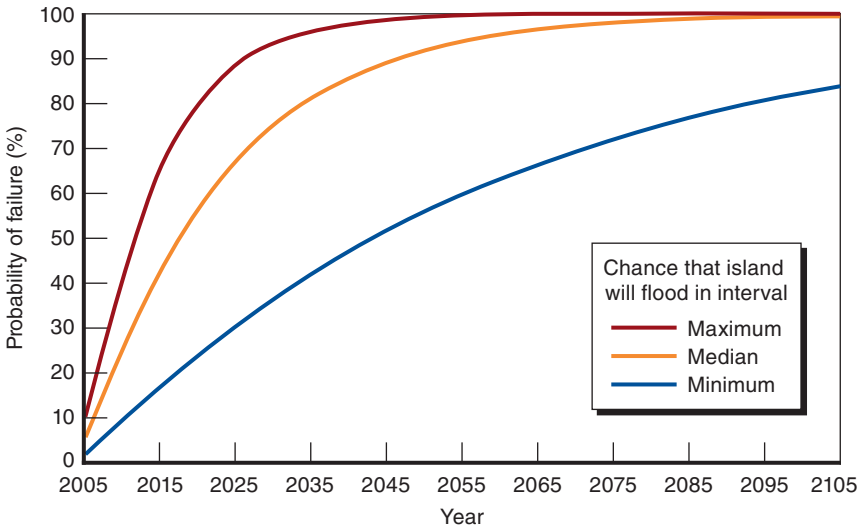
The societal response to the extraordinarily high likelihood that many islands will fail in the future will presumably depend on the costs of mitigating risk. To give a sense of the sums involved, we evaluated the costs and benefits of upgrading and repairing the 34 core Delta agricultural islands (Appendix B).<sup>6</sup> As a starting point, it is useful to note the costs of upgrading the islands to federally mandated standards for Delta agricultural levees. This standard, known as PL 84-99, raises

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<sup>5</sup> Proposition 1E and Proposition 84 allocate nearly \$5 billion for flood management investments in the state as a whole, with the lion's share for the Central Valley's flood control system. Proposition 84 has earmarked \$275 million for the Delta, and some funds from Proposition 1E are also likely to be used in this region.

<sup>6</sup> For this analysis, we excluded two urban islands (Bethel and Hotchkiss) that are included in Figure 2.1.





SOURCE: Authors' calculations using data from URS Corporation and J. R. Benjamin and Associates (2007b).

NOTE: The chart plots the cumulative probability of failure from earthquakes or floods some time during the period up to the years shown.

**Figure 2.1—Cumulative Likelihood of Island Flooding over Time for 36 Core Delta Islands**

levees approximately six inches over basic state Hazard Mitigation Plan standards and reduces their interior side slope to enhance stability and resist seepage erosion. Upgrading to PL 84-99 standards was set as a goal for the CALFED levee program, but few funds were actually allocated to the effort. In today's dollars, the cost of this upgrade is estimated to exceed \$1.4 billion. This sum could be an underestimate, because it presumes that the project levees already meet this standard. Moreover, as the Jones Tract example illustrates, levee repairs for an individual failure can run into the tens of millions of dollars.

To help assess how best to prioritize public spending on Delta levee upgrades and repairs in an increasingly risky future, we developed a simplified Levee Decision Analysis Model. Using annual failure probabilities for today's conditions and values for land and other assets contained in draft DRMS documents and other sources, we estimated the net expected costs of (1) no upgrading of current levees, (2) upgrading

levees to PL 84-99 standards, (3) adding an additional foot in height above PF 84-99 standards to protect levees from sea level rise (at a 20% premium over PL 84-99 costs), and (4) repairing versus not repairing island levees once they fail. The decision to make levee upgrades or repairs weighs the costs of these investments against the economic value of the assets on the island.

Where the net expected costs of levee upgrades and repairs exceed the expected economic production of an island, additional upgrade and repair investments are unlikely to be justifiable from a statewide economic perspective. Local reclamation districts and the individual landowners on these islands would presumably not be restricted from making such investments in their property, although this would likely be an unsound business investment. This analysis assumes that the state would continue modest investments in levee upkeep through the subventions program, regardless of the upgrade or repair status of any levee.

Although these calculations are preliminary and represent one of many potential approaches to prioritizing levee investments, they are sufficient to demonstrate several key points. First, based solely on net expected cost, it is most cost-effective for *all* islands analyzed here to forgo investment in major levee *upgrades*, even when the value of buildings and infrastructure assets is included in island values. This surprising result stems from two factors. First, levee improvement costs are high; upgrade costs often exceed the current land value of the island. Even if land and asset values were increased significantly, upgrades would remain uneconomical. Second, even rather expensive upgrades create only marginal improvements in levee reliability and do not substantially reduce the frequency of levee failures. According to Delta engineers, upgrading to PL 84-99 standards reduces failure probabilities from high water events by only approximately 10 percent and does little to improve performance during earthquakes. Implausibly large increases in levee reliability would be needed to make Delta levee upgrades economically worthwhile.

Second, it is not cost-effective to *repair* many Delta islands after levee failures. In Figure 2.2, the decision on levee repairs is weighed against the economic value of land (mainly farmland) on the island. In Figure 2.3, the value of other assets (houses and other buildings plus roads and

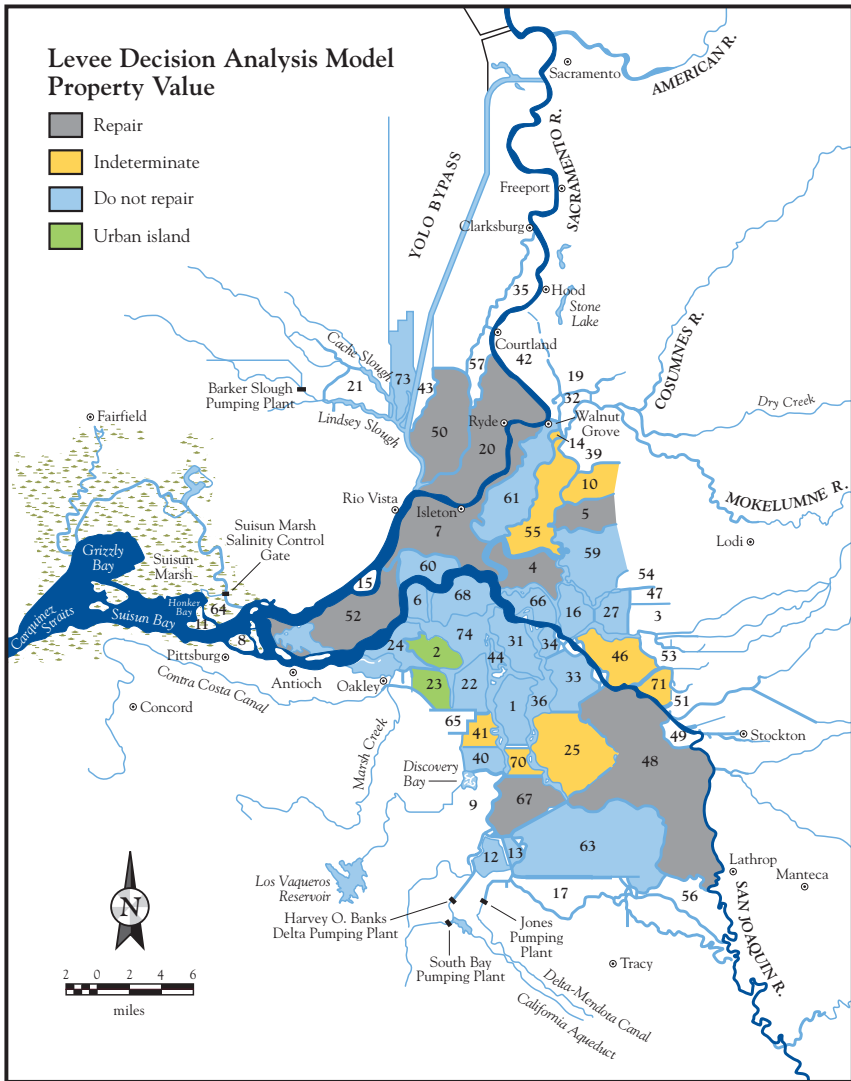
other infrastructure) is included in the economic value of island assets.<sup>7</sup> Figure 2.3 also highlights the five western islands that may be critical for maintaining through-Delta exports, as described below. In the figures, islands are classified as “do not repair” when the costs of *not* repairing a levee breach (including loss of the assets and mitigation of potential effects on levees on neighboring islands) is at least \$50 million lower than the costs of repair. For islands classified as “repair,” the inverse is true. “Indeterminate” islands are those for which the difference in cost between repairing and not repairing the island lies below \$50 million. The inclusion of assets other than land changes the picture for some islands that contain valuable infrastructure, such as Orwood Tract (#40), Woodward Island (#70), and Jones Tract (#25), which contain a railroad line. But roughly half of the islands fall into the “do not repair” category following failure, even when other assets are included in island values. For many of these islands, repair costs are high relative to overall island value.<sup>8</sup>

This analysis does not account for the importance of specific islands for purposes other than local economic activity (primarily farming) and infrastructure (notably road and rail). We excluded islands with substantial urban settlements, such as Bethel Island (#2) and Hotchkiss Island (#23) (shown in green in the figures); such locations would likely merit upgrading to higher urban standards to protect both property and public safety. For the included islands, we did not consider the value of specific islands for terrestrial or aquatic habitat, such as sandhill crane habitat on Staten Island (#55) or social/cultural values, such as legacy towns like Isleton and Walnut Grove. Inclusion of such values—which are difficult to quantify—could raise the cost of protecting some islands. Nor did we include the increasing drainage and pumping costs for Delta islands likely to accompany

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<sup>7</sup> In addition to buildings, some infrastructure assets are privately owned (rail lines, electricity and gas lines). Other assets are owned by local public agencies (e.g., the Mokelumne Aqueduct, which belongs to the East Bay Municipal Utilities District). Insofar as the values of nonstate assets make it cost-effective to repair levee breaches, it is not clear that state taxpayers (as opposed to landowners, shareholders, and ratepayers) should provide the funds.

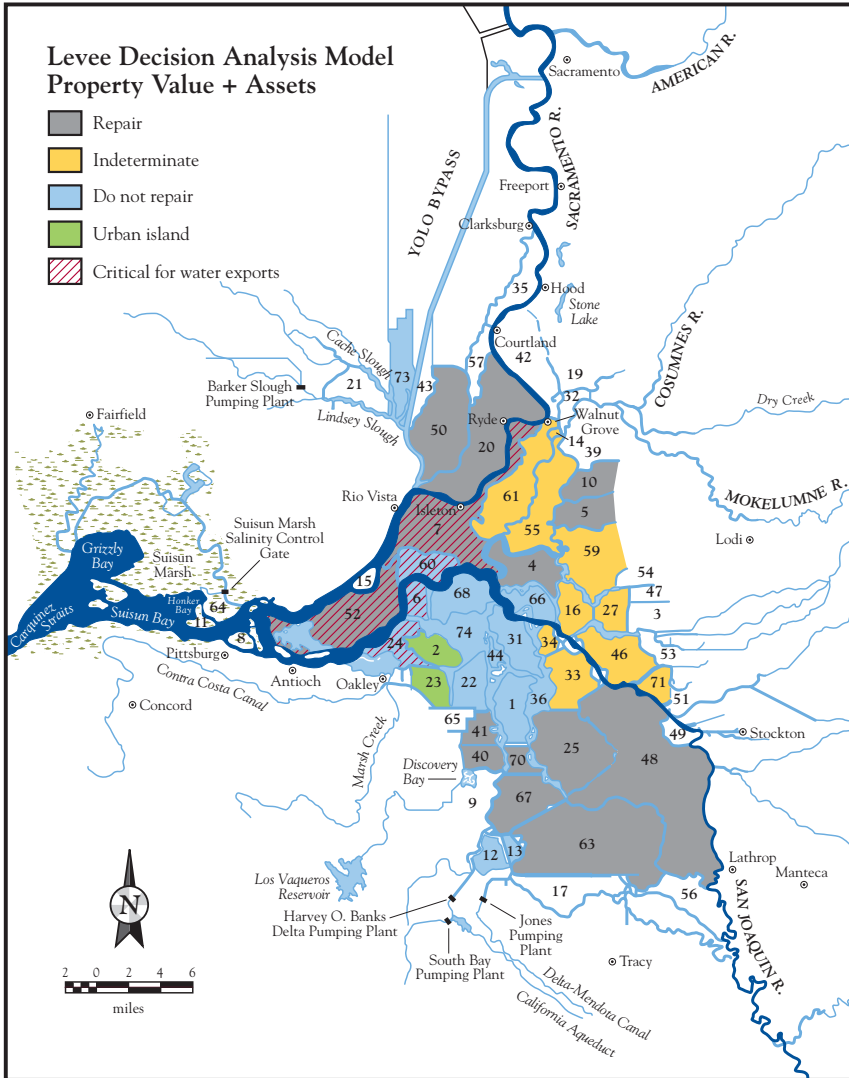
<sup>8</sup> Although the 2004 Jones Tract repair is often cited as an example of such a case, its total asset value (\$550 million) is significantly higher than the costs of repair (\$90 million). Current land values are much lower (\$42 million). (See the spreadsheet accompanying Appendix B.)



SOURCE: Appendix B.

NOTE: For a guide to island names, see the Delta island map key at the beginning of the report.

**Figure 2.2—Repair Versus No Repair Decision for Flooded Delta Islands (Property Values Only)**



SOURCE: Appendix B.

NOTE: For a guide to island names, see the Delta island map key at the beginning of the report.

**Figure 2.3—Repair Versus No Repair Decision for Flooded Delta Islands  
(Property and Asset Values)**

continued subsidence and sea level rise, which will probably lower Delta land values over time.

Finally, and perhaps most significantly for Delta water management debates, we did not explicitly consider the value of Delta islands for maintaining water quality for export facilities and in-Delta uses. However, as discussed further in Chapter 4, some water quality modeling efforts suggest that only the five westernmost islands could be critical to maintaining water quality for through-Delta exports (highlighted in Figure 2.3). In contrast, islands in the central, eastern, and southern Delta could remain flooded following levee failure without significant effects on the quality of water exported from the Delta.<sup>9</sup> This finding is contrary to conventional wisdom, which assumes that most islands of the western, central, and southern Delta are important for maintaining water exports.

The draft DRMS study estimates that upgrading the western islands to be either repairable following a major earthquake or resistant to earthquakes would cost from \$3.6 billion to \$5.2 billion, respectively. As discussed in Chapter 4, the benefits of these upgrades would be limited in time, because sea level rise will eventually degrade Delta water quality or require greater net outflows even if the western islands remain intact.

## A Future Different from the Past

The current Delta, with its elaborate network of channels, subsided islands, and managed inflows and exports, is an unstable system highly vulnerable to perturbation. Geologically, this vulnerability is reflected in the high probability of island flooding. Biologically, this vulnerability is reflected in the recent decline in many native Delta species. If current risks hold, most Delta islands are highly likely to flood some time during the next several decades. Unmanageable processes external to the Delta, such as earthquakes, climate change–influenced sea level rise, and increased flood flows, are being exacerbated by human activities, such as land uses

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<sup>9</sup> Unplanned failures of these interior islands during the dry times of the year could still cause water quality problems associated with the “big gulp”—as saltwater is drawn into the Delta to fill the space in the subsided islands. This problem might be largely avoided if the islands either flood during high freshwater inflow periods or are purchased by the state or some other entity and preflooded.

that increase subsidence. All these drivers point to increased risks of Delta island flooding.

The resiliency of the Delta in its current state depends on its ability to self-adjust and the ability and willingness of Californians to maintain all or parts of the status quo. Unlike natural estuarine or floodplain systems, the Delta's artificial landscape cannot self-adjust to rising sea levels, earthquakes, land subsidence, and higher inflow extremes. Additionally, as others have also found (Logan 1989, 1990a, 1990b), the cost of maintaining current levees outstrips the value of many Delta islands, all available bond funds, and, in all likelihood, the willingness of the public to continue subsidies as failures and costs escalate. It is more cost-effective to invest selectively in Delta levees to protect high-value lands, critical infrastructure, and, depending on the final conveyance choice, islands that support export water of acceptable quality, and to let those lower-value islands without compelling state interests eventually flood and return to aquatic habitat.

This combination of natural forces and artificial conditions created by human activities points toward an inescapable conclusion: The Delta is undergoing a fundamental transformation—one that could accelerate with catastrophic levee failures. The new Delta will significantly differ from the marshy Delta of the early 19th century or the agricultural Delta of the 20th century. The third-generation Delta of the 21st century will likely have large tracts of open, deep (more than 20 feet) water, particularly in the western and central Delta. Islands crucial to state infrastructure, water supply, or ecosystem goals will presumably be prioritized for public investments in maintaining and upgrading levees or modifying or relocating infrastructure. This fundamental and inevitable change will have significant ramifications for all aspects of Delta land and water use.





### 3. Delta Water Export Strategies

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“It is probable that serious objections would be raised to any structure which might have the effect of seriously disturbing or eliminating commercial and recreational fishing in the upper bay and rivers.”

*Raymond Matthew (1931), Economic Aspects of a Salt Water Barrier Below the Confluence of Sacramento and San Joaquin Rivers*

Changes in the Delta are inevitable, given the unstoppable processes of sea level rise, land subsidence, earthquakes, and a warming climate bringing larger floods. As discussed in Chapter 2, these changes pose grave questions about future land uses in many parts of the Delta. Anticipating these changes is also critical for managing California’s water supplies, given the Delta’s central role in moving water from Northern California watersheds to farmlands and cities south and west of the Delta. Recent water exports from the Delta have ranged from five million to six million acre-feet (maf) per year, supplying a large percentage of water used in the Bay Area, the southern Central Valley, and Southern California. On average, these exports account for about 15 percent of natural flows into the Delta watershed and 25 percent of Delta inflows after reductions from upstream diversions (Lund et al., 2007).

The decision of how to manage water exports from the Delta will determine much of the future of California’s water system statewide and will also be central in defining opportunities and alternatives for managing the Delta ecosystem.

The question of how to export water from the Delta has been debated and analyzed since the 1920s. The first major public policy decisions date to the 1920s and 1930s, when the state and later the federal Central Valley Project (CVP) launched the policy of moving water through the Delta to importing regions (Department of Water Resources, 1930; Matthew, 1931a, 1931b). A proposal to alter this basic system, by conveying water around the Delta through a peripheral canal, was overwhelmingly rejected by Northern California voters in 1982 (Lund et al., 2007). This defeat strongly influenced the subsequent two decades of Delta policy,

which has tried to fix the system’s increasing environmental problems while maintaining the basic “through-Delta” system of moving water to the pumps. Given the recent, rapid declines in the Delta’s native fish populations and improved understanding of the fragility of its levees, the issue of how (or whether) to export water from the Delta has arisen again.

Only four approaches exist for the management of Delta exports: (1) continue pumping exports through the Delta (the current policy), (2) divert water upstream and convey it around the Delta through a peripheral canal, (3) combine the current through-Delta pumping strategy with a peripheral canal (so-called “dual conveyance” or “dual facility”), and (4) end exports altogether. In this chapter, we describe the main elements of each alternative and highlight some key economic and environmental considerations. Later chapters delve further into these issues. Our analysis of these alternatives intentionally takes a very broad view, giving only limited attention to the many details of implementation (such as size, operation, and accompanying mitigations). Although the details will affect the ultimate performance of each alternative, many details can be worked out only after a strategy is chosen.

Readers of our *Envisioning Futures* report will find that these four broad water export strategies cover the nine alternatives and hybrid options discussed therein. This new, simpler categorization of options (Table 3.1)

**Table 3.1**  
**Water Export Strategies in the Current and Previous Reports**

<i>Envisioning Futures</i> Report Alternatives	<i>Comparing Futures</i> Report Category
1. Levees as Usual	Continued Through-Delta Exports
2. Fortress Delta	Continued Through-Delta Exports
3. Seaward Saltwater barrier	Continued Through-Delta Exports
4. Peripheral Canal Plus	Peripheral Canal
5. South Delta Restoration Aqueduct	Peripheral Canal
6. Armored-Island Aqueduct	Continued Through-Delta Exports
7. Opportunistic Delta	Continued Through-Delta Exports
8. Eco-Delta	Continued Through-Delta Exports
9. Abandoned Delta	No Exports
Hybrid alternatives	Dual Conveyance

spans all possible strategies, making it easier to compare the economic and environmental consequences of alternative Delta futures.

## Exporting Through the Delta

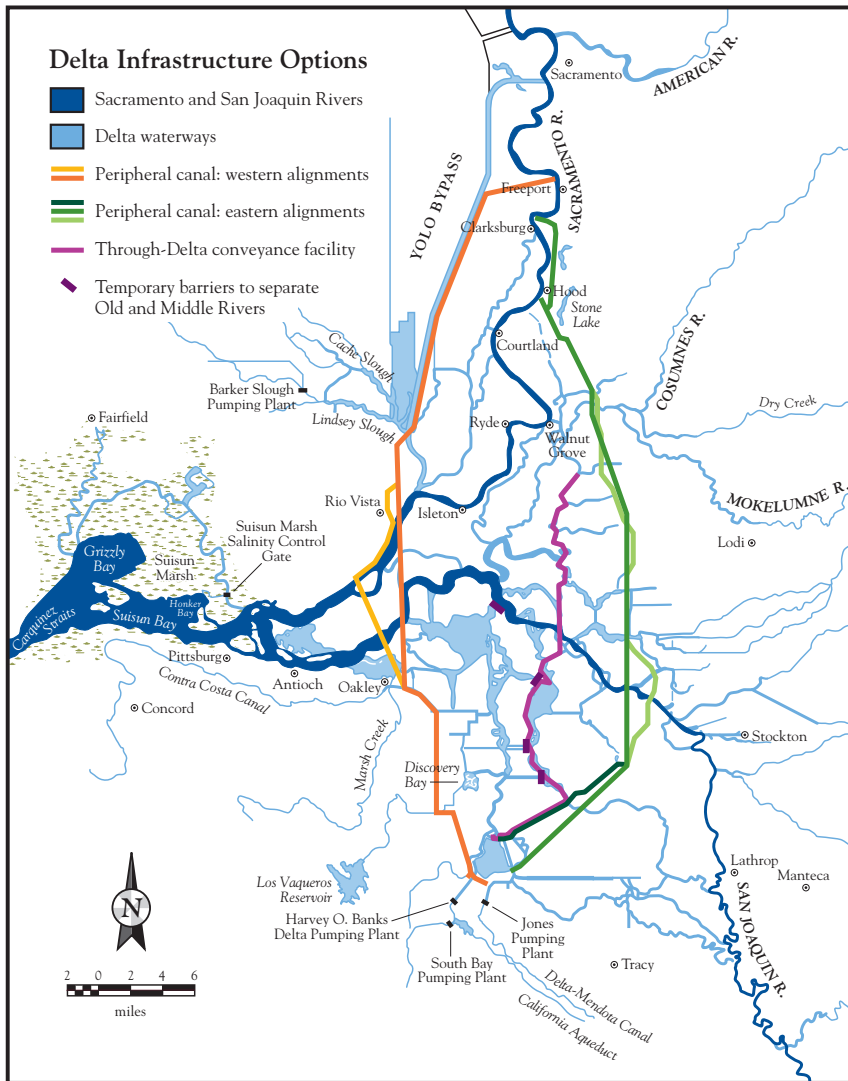
The Delta has four major water export locations (see Figure 3.1). In order of their average export volumes per year in millions of acre-feet or thousands of acre-feet (taf), these are the State Water Project's (SWP) Banks Pumping Plant (3 maf), the federal CVP's Jones Pumping Plant (2.5 maf), Contra Costa Water District's (CCWD) federally owned Contra Costa Canal (120 taf), and the SWP's Barker Slough Pumping Plant, serving the North Bay Aqueduct (60 taf). In addition, hundreds of small diversions are used to irrigate Delta farmland (totaling about one maf per year).

Although this water system has provided reliable water supplies for many decades, it has not been without problems. There is growing evidence that the larger points of diversion (or intakes) have harmed important aquatic species in the Delta by entraining (trapping) fish and by disrupting natural flow patterns within the Delta (Chapter 5). At the same time, Delta water quality is becoming increasingly problematic for both human and agricultural uses (Chapter 6).

Many alternatives have been discussed for modifying the geometry of the Delta, changing Delta inflows and pumping operations, and constructing and operating flow regulation structures to improve flows and water quality (Department of Water Resources, 1957; Jackson and Paterson, 1977; Orlob, 1982; Lund et al., 2007). Even physical saltwater barriers have been proposed.<sup>1</sup> These alternatives imply a wide range of costs for construction, operations, and reductions in exports. They would also have an uncertain and potentially wide range of effects on fish. Indeed, some alternatives nearly amount to a through-Delta alignment for a peripheral canal in their degree of flow isolation from the surrounding Delta (Figure 3.1).

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<sup>1</sup> Physical seawater barriers have long been considered for the Delta (Department of Water Resources 1930; Matthew, 1931a, 1931b) and are common worldwide for dealing with storm surge problems. Lund et al. (2007) rule out permanent barriers because of their likely environmental and economic costs. There has been some recent discussion of closable salinity gates to interrupt the "big gulp" of sea water accompanying major levee failures of subsided islands. This variant would be expensive and unreliable in an earthquake failure. Physical barriers might resolve some water quality problems for water users but would not address worsening ecosystem problems.



NOTE: The orange and green lines show possible western and eastern alignments for a peripheral canal, respectively. The purple line shows possible through-Delta channel reinforcement, to be used alone or as part of a dual conveyance system.

Figure 3.1—Some Infrastructure Options for Long-Term Export Alternatives

As sea level continues to rise and more islands permanently transition to open water, the frequency and quantity of water available from through-Delta pumping will diminish (Chapter 4).<sup>2</sup> This long-term loss of export capability can be reduced or delayed by diversion modifications, changes in Delta channels, and changes in operations in the Delta and upstream. Such changes will be difficult to accomplish given the potential effects on Delta fish species. Nevertheless, a series of short-term solutions might keep through-Delta exports viable for some time.

## Exporting Around the Delta

Currently, about 11 maf per year of water is taken for “consumptive uses” upstream of the Delta in the Sacramento, San Joaquin, and eastern Delta watersheds—over 25 percent of the Delta’s average natural inflows.<sup>3</sup> This includes such major diversions as the Tehama-Colusa Canal on the western side of the Sacramento Valley, the Friant-Kern Canal on the eastern side of the San Joaquin Valley, San Francisco’s Hetch Hetchy Aqueduct, East Bay Municipal Utilities District’s Mokelumne Aqueduct, and many smaller surface and groundwater diversions throughout the northern and southern Central Valley. As far back as the 1920s, upstream uses were sufficiently large to affect flows and water quality in the Delta (Department of Water Resources, 1995).

A peripheral canal would stop current diversions of water for export from the southern Delta, adding them instead to the upstream diversions. Many export users and local water users would presumably connect to the canal. Various approaches to a peripheral canal have been proposed since the 1940s (Jackson and Paterson, 1977; Lund et al., 2007). Earlier peripheral canal designs were intended to expand water exports, but few today believe that a peripheral canal could be used to significantly expand Delta exports. Today’s discussions include several motivations for a canal, most of which also have been considered in times past: (1) improving the

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<sup>2</sup> To date, a few Delta islands have been allowed to remain permanently flooded: Sherman Lake (1875), Franks Tract (1930s), Mildred Island (1983), Liberty Island (1998), and several other smaller islands.

<sup>3</sup> Consumptive water uses are diversions of water withdrawn but not returned downstream. Upstream users actually divert a considerably higher volume, but much is returned to the rivers before they reach the Delta.

quality of exported water, (2) reducing the vulnerability of water supplies to Delta levee failures, and (3) making the water supply system independent of the often conflicting demands of the Delta's ecosystem.

Moving the point of diversion of export water to an upstream location could benefit the Delta's ecosystem by ending entrainment of Delta fish and other organisms in the large southern Delta pumping plants and reducing the unnatural flow patterns in the Delta created by the pumps, which can disrupt the distribution of aquatic organisms. It would also allow more variable and environmentally beneficial management of the Delta, which would then no longer need to be kept fresh year-round to supply the pumps. However, such upstream diversions also would reduce the flows of Sacramento River water into the Delta and would reduce the dilution of polluted San Joaquin River water in the southern Delta. In addition, the new intakes, if not carefully designed and managed, would entrain salmon and other fish in the lower Sacramento River. The various changes in water quality within the Delta itself, although potentially beneficial to important fish species, would pose a problem for Delta farmers unable to connect to the canal for fresh water.

## Dual Conveyance

A hybrid of the first two strategies is often referred to as dual conveyance or a dual facility. This approach combines elements of infrastructure and operations from continued through-Delta pumping and a peripheral canal (Figure 3.1). The general idea is that a hybrid provides greater operational flexibility. When fish of concern are near one intake, the other intake can be used for exports. Similar benefits from redundancy might occur with respect to earthquakes, floods, and other events. With two intakes, greater overall export volumes might also be possible when large amounts of water are available, as long as near-Delta conveyance and storage capacity can accept the larger volumes. Because a dual facility relies on keeping the Delta fresh enough for the pumps, it also provides better guarantees of water quality for Delta farmers than would a peripheral canal alone.

With sea level rise, increasing water quality concerns, and the increasing likelihood of additional permanently failed islands, the occasions when through-Delta pumping would be available are likely to diminish.

This effect might be slowed by modifying the intakes and Delta channels or increasing inflows into the Delta to improve water quality at intake locations. A wide range of proposals exist and others are being developed to allow permanent or interim use of through-Delta pumping, at costs ranging from a half billion dollars to almost \$10 billion.<sup>4</sup> Even with improvements, through-Delta pumping is likely to export less water over time. As this happens, progressively more water could be diverted through the peripheral canal. Alternatively, California could become partially weaned from dependence on Delta and Sacramento River water because of the gradual, long-term reduction in exports.

## Ending Delta Exports

A final logical, if extreme, alternative is to stop exporting water altogether. Ending all exports would solve the export-related problems of fish entrainment and confusion stemming from unnatural flow patterns (Chapter 5). Presumably, ending exports also would increase net Delta outflow from the Sacramento River watershed, something potentially beneficial for fish, although there is no guarantee that upstream users would not then take more water for use in the Sacramento Valley (Chapter 7). Upstream users of San Joaquin and Tulare Basin river water would face great incentives to increase diversions and transfers to supply replacement water to Southern California urban agencies and farmers in the southern Central Valley, perhaps creating additional flow and quality problems for the San Joaquin River.

Flood management, environmental flow, and water temperature management (for salmon) on the Sacramento River and its tributaries, the Trinity River, and some locations on the San Joaquin River and its tributaries would be reshaped if water exports ended. Eliminating the need to supply water for Delta exports from these reservoirs would add flexibility to release schedules for in-basin flood control, water supply, and water temperature and quality management.

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<sup>4</sup> See Department of Water Resources (2008) for a series of cost estimates on through-Delta improvements ranging from \$1 billion to \$10 billion. A lower estimate of roughly \$500 million in improvements was developed by one water agency dependent on Delta exports.

However, ending Delta exports also would impose great financial and economic burdens on water users south and west of the Delta. The costs of a catastrophic outage of water exports would be immense, and even the much lower cost of a planned weaning of water users dependent on Delta exports would be considerable (Chapter 6). The end of water exports also would impose significant financial losses on agricultural water users north of the Delta. With the advent of water markets, many northern farmers have gained financial stability and revenues from leasing their water to users south of the Delta. Northern California's agricultural sector would lose these benefits with the end of water exports.

In practice, ending exports would probably not occur at once, unless an extensive earthquake caused a failure. If ending exports became a planned and phased-in policy, accompanied by expansions in conveyance connections, wastewater reuse, and perhaps seawater desalination, its costs would likely be far less than the costs of a catastrophic and unanticipated termination of exports associated with extensive and sudden failure of Delta levees.

## **Water Exports and the Delta's Economy**

The local economy of the Delta is undergoing substantial changes. Delta agriculture is likely to continue to decline and is most vulnerable and unsustainable in the most subsidized areas. However, elsewhere in the Delta, agriculture is likely to remain strong indefinitely. Recreation is already a major industry in the Delta and is likely to see both change and growth with time. Urban development also is likely to become more important in areas where urbanization is allowed. Most of these trends are unlikely to be affected by changes in export strategy relative to other changes in the Delta brought on by the regional economy and long-term levee failures. The greatest effects of Delta export policies on the local economy are likely to be in shifting some types of recreation locally, changing types of fishing and some boating channels. But shifts in recreational activities and declines in agriculture will occur regardless of which water export alternative is chosen.



## Evaluating the Alternatives

In the remainder of this report, we summarize what is known about the likely performance of each of these four water export strategies and highlight some key economic and environmental implications of their implementation. The context for this evaluation is a Delta which is undergoing a fundamental and inevitable transition. Chapter 4 lays the groundwork for assessing long-term Delta water quality as a result of various natural forces including sea level rise and island flooding and of the introduction of a peripheral canal. Chapter 5 assesses the environmental performance of the alternatives, with a focus on important fish species. Chapter 6 presents an analysis of the costs and benefits of different alternatives for water users and water operations statewide, with a focus on both water quality and integrated supply and demand management. Chapter 7 reviews some major regulatory implications of changing Delta conditions and examines some central governance questions regarding new conveyance infrastructure. In Chapter 8, we pull these analyses together to conduct a summary evaluation and comparison of these four strategies with respect to the two co-equal objectives defined by the Delta Vision Task Force—water supply and the environment—which we will define more precisely as costs to California’s economy and the likelihood that selected fish species will be able to maintain viable populations.



# 4. Hydrodynamics and the Salinity of Delta Waters

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“The invasion of salinity into Suisun Bay as far as the lower end of the Sacramento–San Joaquin Delta is a natural phenomenon which, in varying degree, has occurred each year as far back as historical records reveal.”

*Raymond Matthew (1931), Variation and Control of Salinity in Sacramento-San Joaquin Delta and Upper San Francisco Bay*

Since water exports began in the 1940s, the Delta has been managed to keep its water fresh enough for agricultural and urban uses by export users and in-Delta users. This management—achieved through the release of water from upstream reservoirs and changes in export schedules—can vary daily because of the Delta’s complex and dynamic physical environment. Located on the eastern edge of the San Francisco Estuary and at the mouth of two major rivers, the Delta experiences numerous influences on its water quality: inflows of fresh water, saltwater, and drainage water, with substantial mixing from the tides. The future of water quality in the Delta will remain dominated by these physical forces, acting under new conditions with sea level rise, permanent island failures, and changes in water and land management.

This chapter presents an initial examination of the implications of these new conditions for the salinity of Delta waters. Salinity is of central importance to both agricultural and urban water users. Higher salinities limit crop productivity and the ability to dispose of animal waste and raise drinking water treatment costs (Chapter 6). More variable salinity and flow conditions than those typical under current Delta management would benefit desirable fish species (Chapter 5). Unlike other water quality factors, such as pollutants from agricultural and urban runoff and wastewater treatment plants, salinity is likely to be strongly influenced by the physical forces acting on the Delta.

We use hydrodynamic modeling tools to examine the effects of changes in the Delta’s physical conditions (sea level rise and island flooding) and changes in water management on Delta salinity. The complexities of

the Delta (multiple inflows and outflows of varying salinities, a complex network, and strong tidal influence) require numerical models to explore the effects of such changes. Although even computer models have difficulty representing sufficient physics to properly encompass all major driving forces of the system, these initial results provide important insights about future water quality in the Delta.

We find that Delta salinity is likely to increase significantly as a result of both sea level rise and island flooding, although not all islands appear critical for keeping seawater at bay. Ending through-Delta pumping would substantially increase salinity in the southern Delta, where water quality is heavily influenced by saline drainage water from the San Joaquin Valley. Ending *all* Delta diversions, including the large volumes now diverted upstream, would make the Delta fresher overall, with greater seasonal variability. At current sea level, a peripheral canal or dual facility could increase salinity in some Delta locations and decrease salinity in others. Over time, however, the effects of a canal would be swamped by the increased salinity caused by sea level rise. These findings suggest that physical forces acting on the Delta will increasingly limit the use of Delta waters for farming and urban uses, irrespective of the water management alternatives chosen. Although increased releases from upstream reservoirs and reduced export levels can help to keep the Delta fresh for some time, this continuation of the present strategy will become increasingly costly.

This investigation was performed using available hydrodynamic and water quality knowledge, supplemented with information that could be developed with existing modeling tools. In addition to generating useful preliminary results on the effects of physical changes in the Delta and different water management alternatives, this exercise has shed light on areas where further work is needed to produce more definitive results, which we summarize at the end of this chapter. Appendix C provides greater detail about this modeling work.

## **Modeling Tools and Approach**

We employed two existing computer models to conduct this analysis. The first is a computationally efficient one-dimensional, tidally averaged model called WAM (water analysis module), which was developed by Resource Management Associates, Inc. for modeling work in the Delta

Risk Management Strategy (URS Corporation and Jack R. Benjamin and Associates, 2007a).<sup>1</sup> We use this model to explore the effects of sea level rise and of Delta water management alternatives including the four export options discussed above (through-Delta pumping, no exports, and several sizes of peripheral canal or dual conveyance facilities) and a scenario with “unimpaired flows” (with neither exports nor upstream diversions). These simulations use historical water conditions for 20 water years, from 1981 to 2000, a period including considerable diversity in precipitation, with both one of the wettest periods and one of the longest droughts in recent history.

To explore the effects of permanent island flooding, we use a second, more complete model developed by Resource Management Associates, Inc., for the DRMS flooded-island modeling work (URS Corporation and Jack R. Benjamin and Associates, 2007b). Because this model takes considerably longer to run (480 hours, versus 15 minutes for WAM), we relied on existing simulations for the island-flooding scenarios. These simulations use conditions for a shorter period: the two and a half years between April 12, 2002, and December 31, 2004.

Unless noted, both sets of model simulations assume the same daily hydrologic and operating conditions (reservoir releases, upstream and in-Delta diversions, and exports) that occurred during the simulation periods (1981–2000 or April 2002–December 2004). Both models performed well in comparisons with recorded salinity data at seven locations (Appendix C; URS Corporation and Jack R. Benjamin and Associates, 2007a; Delta Risk Management Strategy, 2007). In addition, the flooded-island model has been successfully applied to other Delta island failures, such as the Jones Tract failure in 2004.

## Comparing Scenarios

In the results presented below, we compare Delta salinity under various scenarios with a base case representing actual conditions from April 2002 to December 2004 (for island flooding) and from 1981 to 2000 (for all other scenarios). The base case represents through-Delta

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<sup>1</sup> To properly mix salt through the channel network, WAM uses dispersion algorithms developed from more detailed but slower three-dimensional modeling work (Gross, MacWilliams, and Nidzicko, 2007).

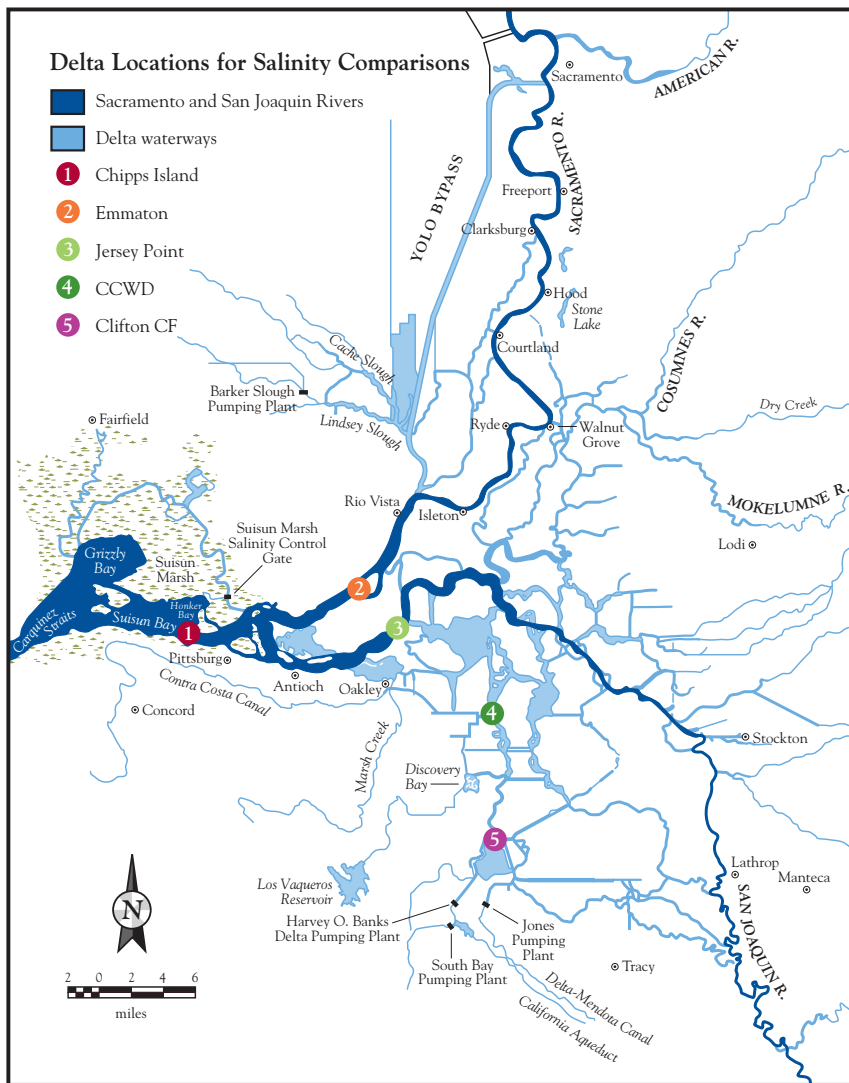
pumping, with all islands intact, at current sea level. Most comparisons are shown in percentage of days each month when water salinity, as measured by the electrical conductivity (EC) of the water, exceeds a prescribed regulatory limit. To capture a range of effects for agricultural, urban, and environmental uses of Delta water, we focus on five locations within the Delta (Figure 4.1): (1) Chipps Island on the Delta’s western edge—a location used to monitor salinity regulations for fish during the springtime (February through June), (2) Emmaton, a northwestern location on the Sacramento River where irrigation water standards are in effect from April through August, (3) Jersey Point, a western Delta site on the San Joaquin River (irrigation standards in effect from April through August), (4) the Contra Costa Water District’s (CCWD) Pumping Plant in the southwestern Delta (more stringent urban standards, year-round), and (5) the Clifton Court Forebay (Clifton CF) in the southern Delta representing exports for the State Water Project (SWP) and the Central Valley Project (CVP) (year-round urban standards and seasonal irrigation standards).<sup>2</sup>

Although the comparisons indicate shifts in the ability to use water for designated beneficial uses, they do not directly demonstrate regulatory compliance (or lack thereof), since the EC limits used here are fixed, whereas for most regulatory standards the limits vary seasonally and by water year type. Also, some of the regulations were not in effect during the entire period of the simulations (in particular, the environmental regulations at Chipps Island did not come into effect until 1999—see Chapter 7).

We begin by comparing through-Delta pumping with the alternatives of ending exports and ending all diversions from the Delta watershed (unimpaired flows), all at current sea level. We then explore the effects on through-Delta pumping of two physical changes in the Delta: sea level rise and island flooding. A subsequent section examines the effects of introducing a dual facility or peripheral canal, at current sea level and with sea level rise.

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<sup>2</sup> The current EC standards for the Delta are contained in D-1641, adopted in 1999. For an overview, see State Water Resources Control Board (2000), Tables 1, 2 and 4 (included in Appendix C).



**Figure 4.1—Locations for Water Salinity Comparisons**

## No Exports and Unimpaired Flows

One alternative considered in this report is to eliminate Delta exports altogether. Extending this logic, it is also of interest to assess the implications on Delta salinity of ending upstream diversions given that nearly two-thirds of diversions occur upstream (Chapter 3). The role of upstream diversions in Delta water quality has been of policy interest since the early 20th century, when the City of Antioch (at the western edge of the Delta) unsuccessfully sued upstream irrigators on the Sacramento River for increasing Delta salinity. Most recently, the Delta Vision Blue Ribbon Task Force has emphasized the importance of considering upstream diverters when seeking a solution to the Delta's environmental woes, as described further in Chapter 7. The results of these simulations are summarized in Figure 4.2, which compares salinity conditions in the through-Delta base case to scenarios with no exports and with unimpaired Delta flows (i.e., flows without exports, upstream diversions, or surface storage).<sup>3</sup>

Although ending exports would substantially increase Delta outflows, it would not uniformly freshen Delta waters. Salinity would decrease in the northern and western Delta (Emmaton and Jersey Point) but would increase significantly in the southern Delta (Clifton CF) without exports. (To see this in Figure 4.2, compare the position of the dark blue line, representing the base case, with the red line (no exports) and the green line (unimpaired flows) at these locations. At Jersey Point, the no exports line does not appear in the figure because salinity limits are not exceeded.) Through-Delta exports reduce southern Delta salinities by diluting higher-salinity San Joaquin River water with the fresher Sacramento River water drawn south to the pumps. In contrast, for unimpaired flows without upstream or export diversions or surface storage releases, dramatic reductions occur in salinity at all Delta locations, except at Emmaton and Chipps in the fall.<sup>4</sup> (Indeed, the salinity reductions are so significant at CCWD and Clifton CF that the green line representing unimpaired flows does not appear in the figure.)

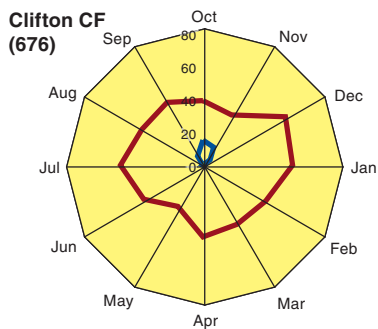
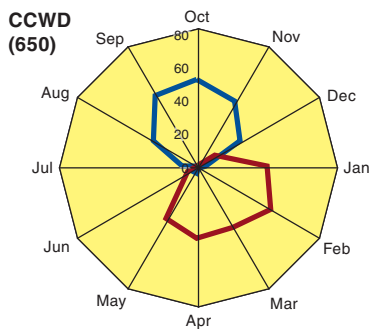
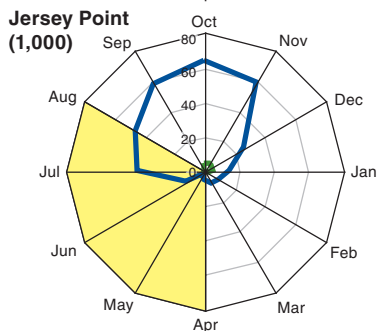
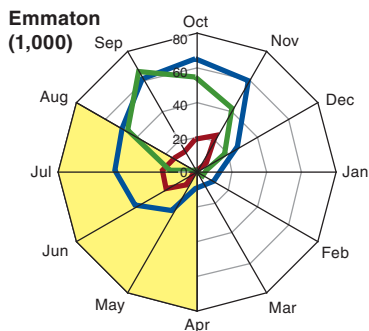
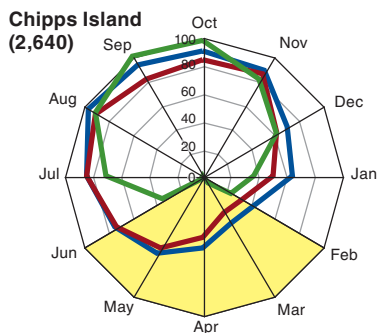
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<sup>3</sup> For the no exports simulation, the base case was modified to set to zero the exports of CCWD, SWP, CVP, and the North Bay Aqueduct (which diverts water at the Barker Slough Pumping Plant).

<sup>4</sup> Because these unimpaired flows were estimated using monthly averaged inflow and salinity data, the results are somewhat muted relative to results that would have been obtained using daily data.



Percentage of days per month above given EC ( $\mu\text{S}/\text{cm}$ ), 1981–2000  
(no sea level rise)



SOURCE: Appendix C.

NOTES: “No exports” shows results with exports from the following locations set to zero: Contra Costa Water District (CCWD in Figure 4.1), SWP and CVP Pumping Plants in the Southern Delta (Banks, Jones, and South Bay Pumping Plants in Figure 4.1), and the SWP’s North Bay Aqueduct (Barker Slough in Figure 4.1). “Unimpaired flows” also sets upstream diversions and surface storage to zero. Shaded areas are periods when compliance with salinity standards is prescribed, although compliance levels vary across water year types. In the no-exports scenario, the specified EC is never exceeded at Jersey Point. In the unimpaired flows scenario, the specified EC is never exceeded at CCWD and Clifton CF.

Figure 4.2—Effects of Ending Exports and Upstream Diversions on Delta Salinity

In the *Envisioning Futures* report, we argued that before Europeans settled the area, the Delta had considerably more seasonal and cross-year variability in salinity than does today's Delta, which is kept fresh enough to meet regulatory standards for water exports year-round. Greater variability can benefit the Delta's native aquatic species (Chapter 5). The unimpaired flows scenario provides some insights into the way the Delta operated before water diversions began, although the Delta it represents is *today's* artificially modified landscape and channel networks rather than the Delta marshlands as they were before European settlement. Even in this modern Delta, salinity levels during unimpaired flows would be more variable than under export conditions in the base case: The western Delta is fresher in the spring and more saline in the fall.<sup>5</sup> The intertidal, tule wetlands of the Delta before its marshlands were diked and drained would have had much more variable flows and salinity patterns across and within years. Flow rates would have been higher when water levels rose above the tule vegetation, and outflows would have been restricted at lower water levels, given the much lower natural channel capacity that existed under low-flow conditions (Baptist et al., 2007). Even with catastrophic island failures, the modern Delta would not revert to the natural Delta of pre-European times, because the islands are now highly subsided and cross channels and deeply dredged shipping channels significantly affect Delta hydrodynamics.

It is not possible to return to the Delta of pre-European times, where conditions were more beneficial for the Delta's native fish species. However, as discussed in *Envisioning Futures* and in Chapter 5, re-creation of more variable water flow and salinity would benefit the Delta's desirable fish. This goal is inconsistent with year-round through-Delta pumping.

## Consequences of Sea Level Rise

Sea level at the Golden Gate of California has been increasing by 0.08 inches per year over the past century. Most climate models project an increase in the rate of sea level rise during the next century (Intergovernmental Panel on Climate Change, 2007). For planning purposes, the CALFED Independent Science Board has recommended

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<sup>5</sup> The western Delta (Chippis Island and Emmaton) would likely have been even more saline in the fall if we had used daily input values.

that the Delta Vision initiative use the mid-range values for sea level rise of 8–16 inches by 2050 and 28–39 inches by 2100 (Mount, 2007). Only very recently have examinations begun of the consequences of sea level rise for Delta salinity distributions.

With sea level rise, and all other conditions being equal, the ocean pushes its higher-salinity (higher-density) water farther into the Delta. Less clear are the potential effects of deeper water, which may reduce the vertical mixing of salinity (with fresh water at the top and more saline water at lower depths). To simulate sea level rise, the initial water elevation throughout the Delta was increased by one and three feet. These simulations all assume continued through-Delta exports at levels experienced from 1981 to 2000.

The results, shown in Figure 4.3, compare the increase in salinity at all five locations with the “base case.” With one foot of sea level rise (the red line), salinity in the Delta may still be low enough for irrigation during the growing season (April to August), but higher levels in the southern Delta (CCWD and Clifton CF), particularly in the fall, would significantly increase the costs of drinking water treatment. With a three-foot sea level rise (the green line), salinity would greatly increase the cost of drinking water treatment and Delta water may be unsuitable for agricultural irrigation. In very dry years, the salinity problems are particularly acute, even with one foot of sea level rise (Appendix C).

One way to counteract increased salinity is to increase net Delta outflows of fresh water, by reducing export and upstream diversions and changing reservoir releases. With one foot of sea level rise, an annual average of at least 475,000 acre-feet of additional Delta outflow would have been required to maintain 1981 to 2000 salinity conditions at the western edge of the Delta—or roughly 10 percent of annual export volumes during that period. With continued sea level rise, the volume of required outflows would continue to increase.

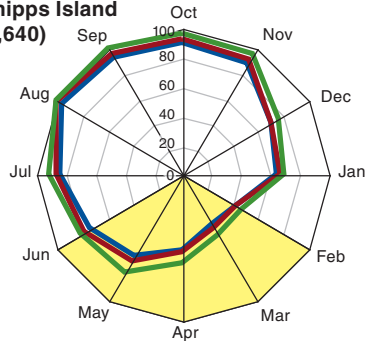
## Consequences of Island Flooding

Over the last 100 years, there have been 166 island failures in the Delta. As a consequence of continued sea level rise, periodic flood flows, deteriorating levees, and earthquakes, islands will continue to fail; and with earthquakes and floods, many could fail simultaneously. As shown

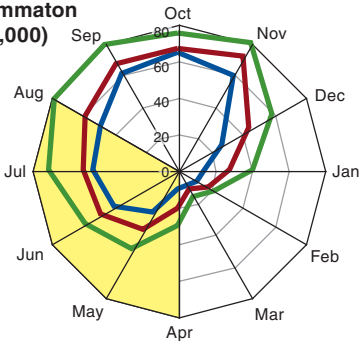
Percentage of days per month above given EC ( $\mu\text{S/cm}$ ), 1981–2000  
(with sea level rise)



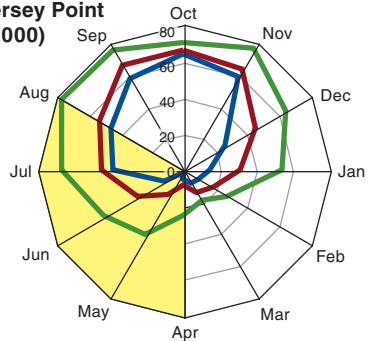
**Chippis Island  
(2,640)**



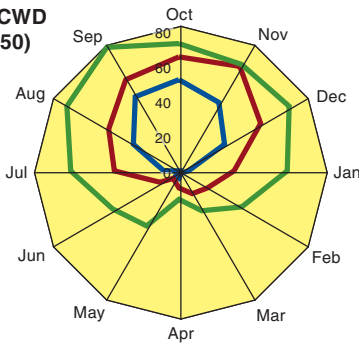
**Emmaton  
(1,000)**



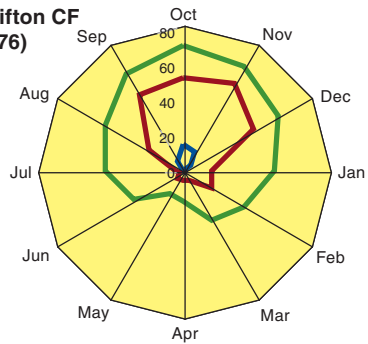
**Jersey Point  
(1,000)**



**CCWD  
(650)**



**Clifton CF  
(676)**



SOURCE: Appendix C.

NOTES: The figure shows average monthly values over the simulation period 1981–2000, with 1981–2000 levels of upstream reservoir operations and Delta exports. Shaded areas are periods when compliance with salinity standards is prescribed, although compliance levels vary across water year types.

Figure 4.3—Effects of Sea Level Rise on Delta Salinity

in Chapter 2 and Appendix B, some flooded islands may not be worth reclaiming if the judgment is based on the economic value of the activities on the islands themselves. However, it is important to model the salinity consequences of leaving islands permanently flooded following failure, to see whether they have strategic value for keeping Delta salinity sufficiently low to permit agricultural and urban water uses.

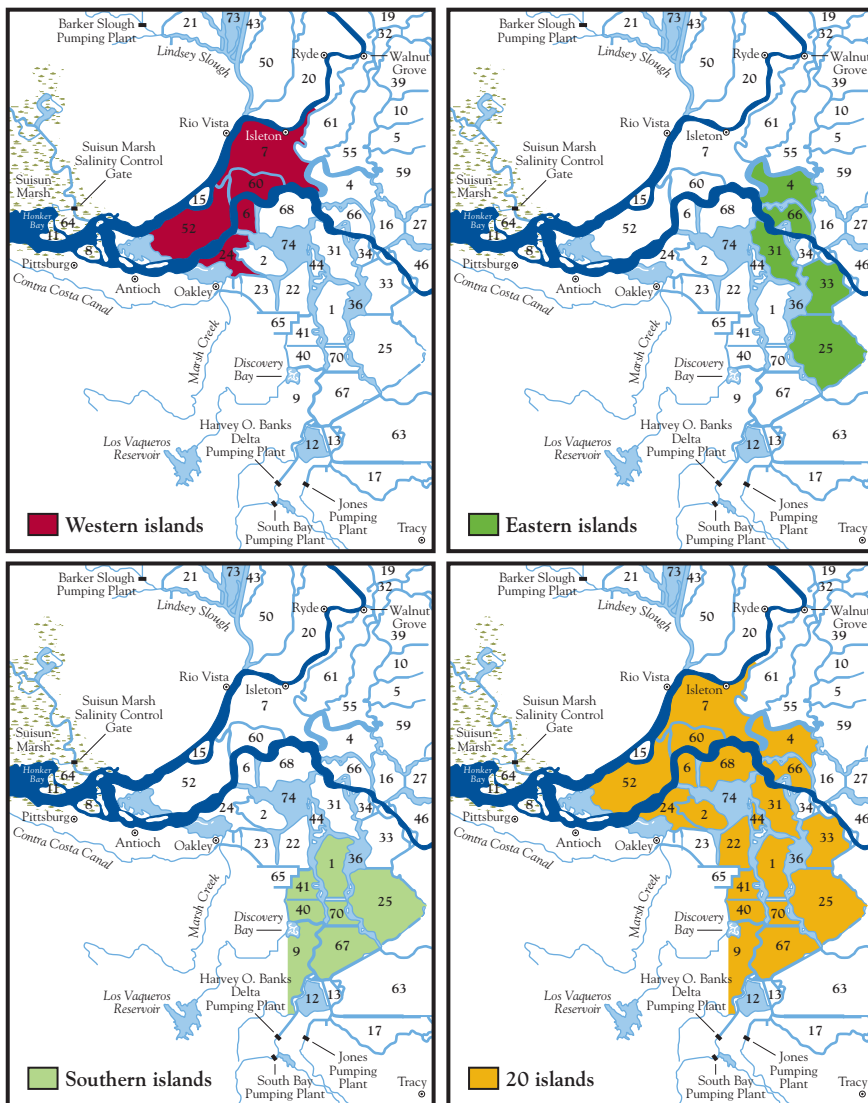
In these simulations, the islands are “preflooded”—filled with water of salinity equaling that in surrounding channels. This depiction represents conditions for an island that has already been flooded for some time; it could also result if the initial flooding occurred during the winter or spring, when significant river flows are available. Four island-flooding scenarios (Figure 4.4) are compared with the base case, which represents through-Delta pumping as it actually occurred from April 12, 2002, to December 31, 2004, with all islands intact:

- Five western islands (Sherman (# 52), Twitchell (# 60), Bradford (# 6), Brannan-Andrus (# 7), and Jersey (# 24)),
- Five eastern islands (Venice (# 66), Mandeville (# 31), McDonald (# 33), Jones (# 25), and Bouldin (# 4)),
- Five southern islands (Palm-Orwood (# 40 and # 41), Bacon (# 1), Woodward (# 70), Jones (# 25), and Victoria (# 67)), and
- Twenty islands (all the preceding islands plus five in the Central Delta: Byron (# 9), Bethel (# 2), Webb (# 68), Holland (# 22), and Quimby (# 44)).

As with the other scenarios, these simulations assume continued through-Delta exports. The results, shown in Figure 4.5, suggest some striking differences in the strategic value of Delta islands for maintaining low salinity levels. The permanent flooding of five western islands increases salinity intrusion to the pumps in the southwest (CCWD) and southern Delta (Clifton CF) and would significantly affect drinking water treatment costs between August and December. In effect, the long-term consequences of permanent western island failures are almost as problematic for export water salinities as the immediate consequences of levee breaches.<sup>6</sup> With

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<sup>6</sup> These failures result in little change at Chipps Island and Emmaton, in part since no breaches were included on the Sacramento side of the islands. The location of island breaches affects where water and salts are transported and reinjected into the Delta with

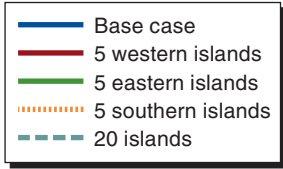


NOTE: For a guide to island names, see the map at the beginning of the report.

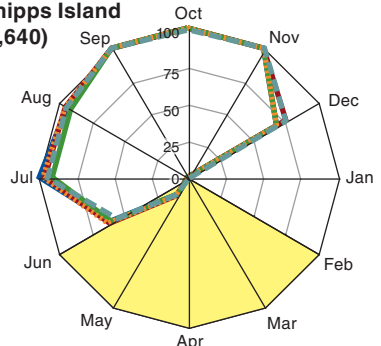
Figure 4.4—Delta Island Flooding Scenarios

each tidal cycle. Only modest changes occur at Jersey Point, because without the “big gulp” of a sudden levee failure, most saltwater is pulled southward toward the pumps.

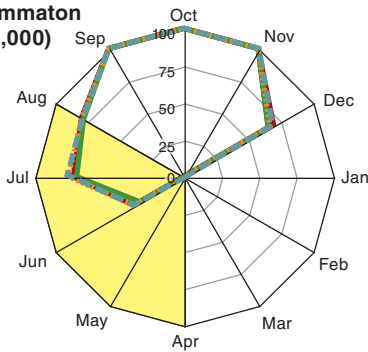
Percentage of days per month above given EC ( $\mu\text{S/cm}$ ),  
 April 12, 2002–December 31, 2004  
 (no sea level rise)



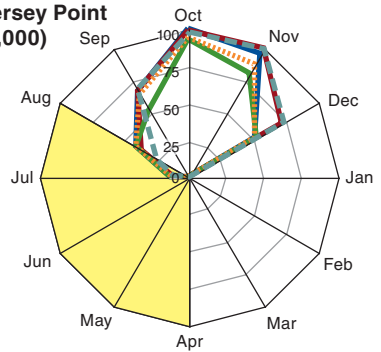
**Chippis Island**  
 (2,640)



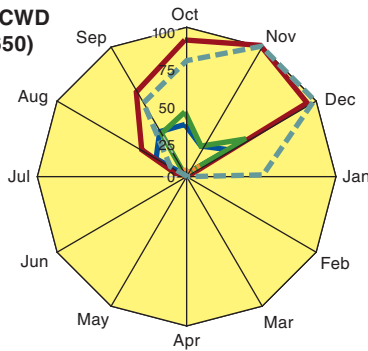
**Emmaton**  
 (1,000)



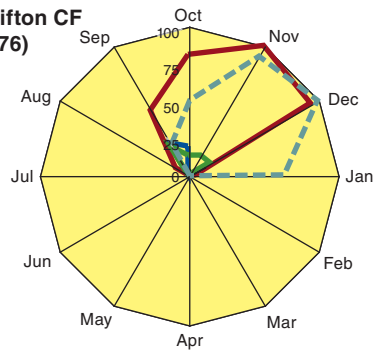
**Jersey Point**  
 (1,000)



**CCWD**  
 (650)



**Clifton CF**  
 (676)



SOURCE: Appendix C.

NOTES: Shaded areas are periods when compliance with salinity standards is prescribed, although compliance levels vary across water year types. At Chippis Island and Emmaton, all five scenarios essentially overlap.

Figure 4.5—Effects of Island Flooding on Delta Salinity

western island failures, more saline water is drawn in from the eastern Bay on flood tides and is then released by the islands during ebb tides into fresher river water, increasing dispersion of the salts.

In stark contrast, the permanent flooding of eastern or southern islands shows little, if any, long-term salinity effects on the Delta. There are even short periods when the failed islands improve southern Delta salinity (CCWD and Clifton CF) by facilitating the flow of Sacramento River and eastside streams (Calaveras, Mokelumne, and Cosumnes) through the Delta toward the southern pumping plants. Since the flooded areas are farther from the Bay than are the western islands, they do not draw as much saline water in from the Bay. There is also considerable eastward infiltration of sea salt from the filling and emptying of flooded western islands with each subsequent tide.

The catastrophic failure scenario, with permanent failures of 20 islands, produces very similar results to the failure of the five western islands, highlighting the importance of the five western islands in maintaining the current conveyance system for water exports. As discussed in Chapter 2, this is a particularly risky prospect, given the high probabilities of failure of these islands by mid-century from flood and seismic activity.

Although time available prevented us from modeling the combined influences of sea level rise and island failure, others involved in modeling the Delta agree that the effects would at least be additive. Thus, by mid-century, Californians are likely to face conditions where large parts of the Delta have become brackish, unusable for either drinking water or agriculture without costly treatment.

## **Consequences of Peripheral Canal Exports**

The potential water quality effects of rerouting some or all exported water from Delta channels to a peripheral canal have been hotly debated for over 30 years. One justification for a canal has been that export users could benefit from lower salinity water by tapping into Sacramento River flows upstream of the Delta. However, water users in the Delta have been concerned that these diversions would increase salinities within the Delta itself. Although reducing or eliminating through-Delta pumping could benefit Delta fish populations, environmental advocates also have



expressed concerns over whether the volume and timing of diversions would sufficiently protect fish.

The peripheral canal proposed to voters in 1982 was a very large facility (up to 25,000 cubic feet per second (cfs)) intended to significantly increase the capacity of water exports from the Sacramento River watershed. Here, we explore a more modest set of alternatives. We assume stability of export volumes at 1981–2000 levels, and we examine several canal capacities, ranging from 2,000 cfs to 15,000 cfs, operated as dual conveyance with some continued through-Delta exports. In these scenarios, the canal takes as much of the daily exports as possible, subject to an environmental constraint requiring a minimum flow on the Sacramento River of 10,000 cfs. We also examine an alternative without this environmental constraint, which operates as an exclusive peripheral canal (PC) that does not use existing Delta pumps (“PC-only”). The PC-only alternative with the same environmental constraint would require new operational patterns for exports and reservoir releases and was not examined here.

The minimum flow requirement on the Sacramento River of 10,000 cfs is introduced to prevent flow reversals, resulting from tidal influences, near potential upstream intake locations. Many organisms take advantage of tidal (bi-directional) flows, moving vertically in the water column to travel much farther on the tidal currents than they could otherwise by their own power on the downstream river current. Locating canal intakes where bi-directional flow occurs could inadvertently draw these organisms through the canal, and a minimum flow requirement on the Sacramento River of 10,000 cfs has been identified as a threshold to avoid this problem (Burau, 2007). Sea level rise will move the location of the limit of bi-directional flow farther upstream. Taking water on ebb flows and not on flood tides could lessen this problem.

### ***Export Quantities and Canal Sizing Issues***

Table 4.1 compares the volumes of exports drawn through the canal and through the Delta for the different export alternatives. Although only the PC-only alternative eliminates through-Delta exports, the two largest canals greatly reduce through-Delta pumping. However, the minimum outflow constraint on the Sacramento River significantly limits the use of the canal in these scenarios. Doubling the canal capacity from 7,500 to

**Table 4.1**  
**Average Water Exports for Four Peripheral Canal Alternatives**  
**(in acre-feet/day)**

Alternative	Water Export Sources		
	Canal Diversions	Through-Delta Diversions	Total Exports
Base case	0	13,500	13,500
2,000 cfs PC	3,100	10,400	13,500
7,500 cfs PC	7,900	5,600	13,500
15,000 cfs PC	8,800	4,700	13,500
PC-only	13,500	0	13,500

SOURCE: Appendix C.

NOTES: Peripheral canal withdrawals are limited by 10,000 cfs minimum flow requirement in Sacramento River for all cases except PC-only. Canal and through-Delta diversions may not sum exactly to total exports because of rounding.

15,000 cfs increases average exports through the canal by less than 1,000 af per day (Appendix C).

However, these results should not be interpreted as justifying a hard limit on the ideal size of a peripheral canal. The scenarios examined here artificially constrain peripheral canal exports by reproducing the timing and quantity of exports that occurred between 1981 and 2000. By re-operating the system—diverting more water during high flow periods—it would be possible to export considerably higher volumes through a peripheral canal while respecting the minimum outflow requirement described above, as long as pumping, canal, and storage capacity were available south of the Delta. On average, the total possible deliveries through a peripheral canal with the minimum outflow constraint were 55 percent higher than the actual volume exported (7.6 maf per year possible versus 4.9 maf per year actual) (Table 4.2). Although diversions of this magnitude are likely infeasible for environmental reasons (since sharp reductions in peak Sacramento River flows would have other consequences), these results illustrate the need to consider operational changes and their effects on the environment before determining export capacity.

There are also environmental reasons for building a larger-capacity peripheral canal to export the same amount of water. Properly managed,

Table 4.2  
Potential Peripheral Canal Exports with Minimum Sacramento Flow Requirements, 1981–2000

Export Volume	Sacramento River Average Flow	Sacramento River Available Flow <sup>a</sup>	Maximum Infrastructure Capacity <sup>b</sup>	Actual Export Volumes	Additional Export Capacity <sup>c</sup>	Potential Additional Exports <sup>d</sup>	Total Possible PC Exports <sup>e</sup>
cfs/day	24,500	16,000	14,900	6,800	8,100	3,600	10,500
af/day	48,600	31,700	29,600	13,500	16,000	7,200	20,700
af/year	17,766,000	11,590,000	10,794,000	4,948,000	5,846,000	2,626,000	7,574,000

SOURCE: Appendix C

<sup>a</sup>Amount available after deducting minimum flow requirement (10,000 cfs).

<sup>b</sup>Maximum possible exports to points south and west of the Delta through the Banks (10,300 cfs) and Jones (4,600 cfs) pumps.

<sup>c</sup>Additional channel capacity (“Maximum Infrastructure Capacity” minus “Actual Export Volumes”).

<sup>d</sup>Minimum of “Additional Export Capacity” and “Sacramento River Available Flow” (calculated daily).

<sup>e</sup>“Actual Export Volumes” plus “Potential Additional Exports.”

a larger facility would enable water to be exported on ebb flows, during higher river flows, and only at times with less risk of environmental harm.

### ***Water Quality Implications of a Peripheral Canal***

At current sea level, the dual conveyance scenarios examined here have relatively modest effects on salinities in the Delta (Figure 4.6).<sup>7</sup> Salinity increases for locations along the Sacramento River (Emmaton), as the reduced river flow allows brackish water to move upstream. Salinity decreases slightly for locations near the San Joaquin River outlet (Jersey Point), as less saltwater is pulled from the west with reduced through-Delta pumping. Only the PC-only scenario significantly increases salinity at the southwestern (CCWD) and southern (Clifton CF) pumping locations, for reasons similar to the no exports scenario examined above; with less fresh Sacramento River water being drawn toward the pumps, southern Delta water salinity is dominated by the more saline San Joaquin River flows.

For users of export water, the water salinity implications of these changes depend on the export blend, because Sacramento River water is so much fresher than San Joaquin River water. At current sea level, continued through-Delta exports with the dual conveyance systems depicted here protect agricultural users in the western Delta along the San Joaquin River (Jersey Point) and the southern Delta (Clifton CF) as well as urban users at the CCWD pumps. However, some additional upstream flow releases would likely be required to maintain agricultural salinity standards at Delta locations along the Sacramento River (Emmaton).

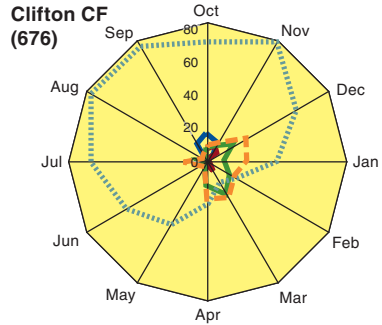
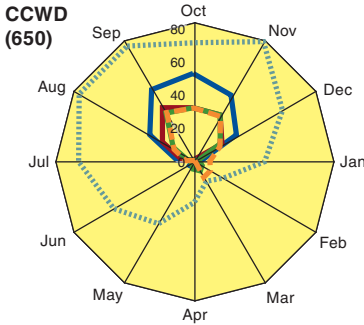
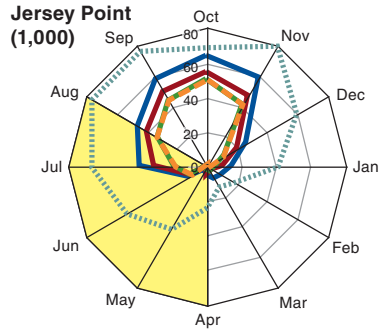
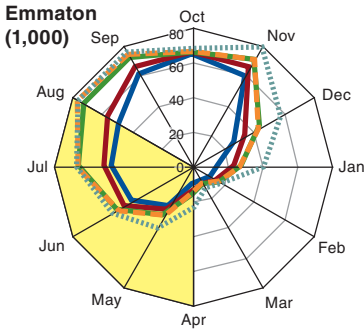
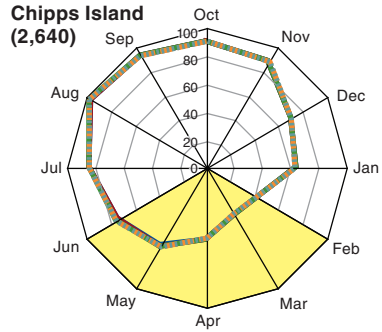
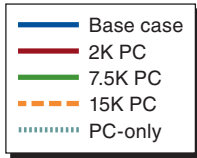
### ***Water Quality with Sea Level Rise and a Peripheral Canal***

These conditions are likely to change significantly with sea level rise, however. Figure 4.7 shows the effects for export users of mixing different proportions of Sacramento River and Delta water with up to three feet of sea level rise. The figure summarizes these effects in terms of the average daily volumes of salt exported in this mix. The results confirm that export water quality deteriorates significantly with sea level rise under the current through-Delta pumping system. A peripheral canal could significantly mitigate these effects by making fresher water available, although it

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<sup>7</sup> Since none of the scenarios changes the net Delta outflow, none produces a significant change in salinities at Chipps Island.

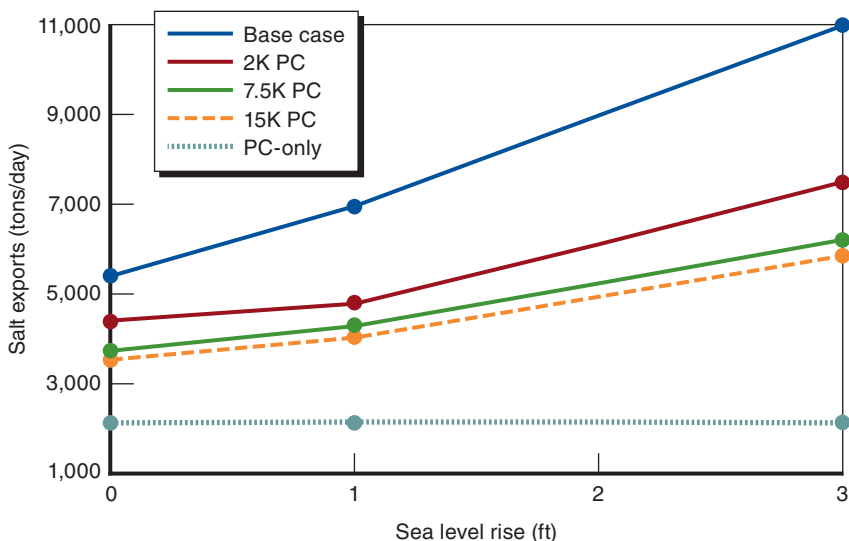
Percentage of days per month above given EC ( $\mu\text{S}/\text{cm}$ ), 1981–2000 (no sea level rise)



SOURCE: Appendix C.

NOTES: The dark blue line is the base case of through-Delta pumping; other colors show the results with the following amounts of peripheral canal capacity and a 10,000 cfs minimum flow on the Sacramento River: 2,000 cfs (red), 7,500 cfs (dark green), and 15,000 cfs (hatched orange). The light blue hatched line shows the results of the PC-only alternative (15,000 cfs with no limit on removal of water from the Sacramento River). All scenarios overlap at Chipps, since net Delta outflow does not change. Shaded areas are periods when compliance with salinity standards is prescribed, although compliance levels vary across water year types.

Figure 4.6—Effects of a Peripheral Canal on Delta Salinity, at Current Sea Level



SOURCE: Appendix C.

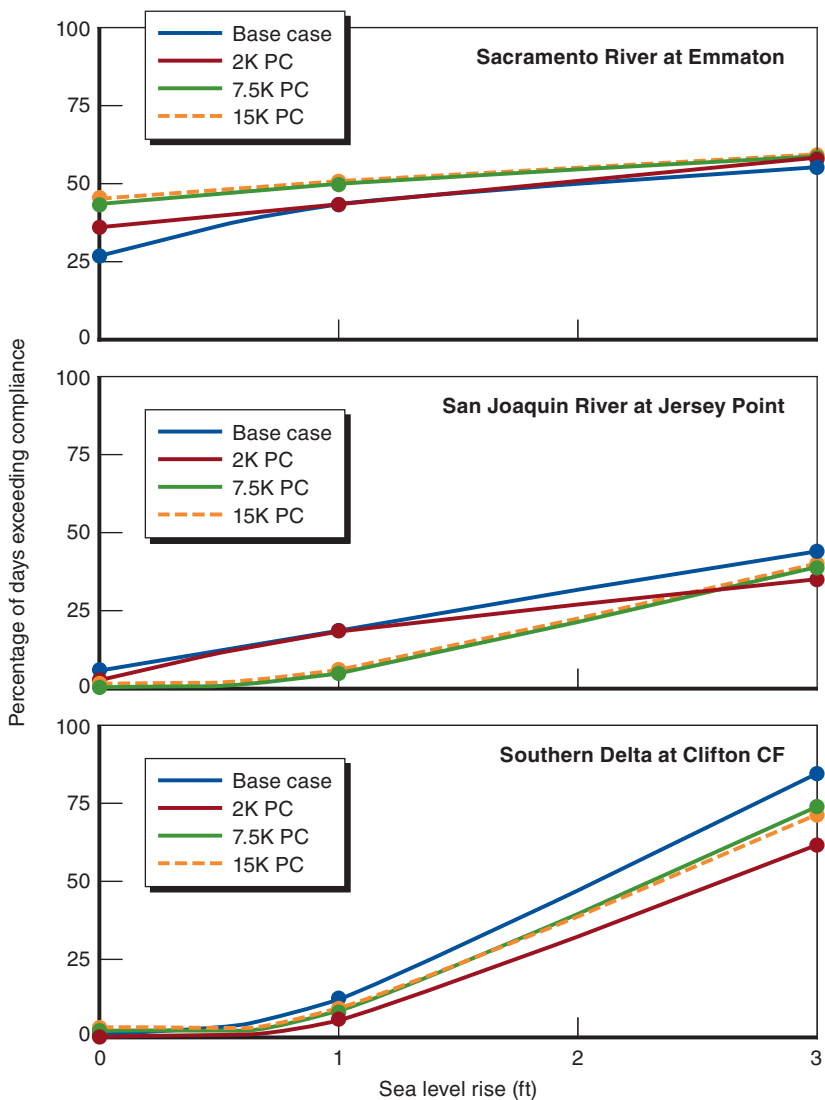
NOTE: The calculations assume 13,547 af/day of exports on average (the 1981–2000 average).

**Figure 4.7—Salt Exports for Different Peripheral Canal Capacity and Sea Level Rise Scenarios**

would not eliminate the effects of sea level rise if it is operated as a dual conveyance facility. Re-operation of the system (changing the timing of exports and reservoir releases) might improve these results.

To assess the effects of these changes on agricultural pumping in the Delta, Figure 4.8 shows the percentage of days during the 137-day irrigation season (April 1 through August 15) that the compliance EC levels would be exceeded at Emmaton, Jersey Point, and Clifton CF.<sup>8</sup> The results suggest that the effects of different peripheral canal alternatives on Delta salinity will diminish over time as the sea level rises. Under current conditions, only western Delta farmers on the Sacramento River side of the Delta (Emmaton) suffer serious salinity consequences from a peripheral canal, whereas salinity conditions actually improve for western Delta

<sup>8</sup> Although current salinity standards at the Clifton CF location are constant over the irrigation compliance period (at 1,000  $\mu\text{S}/\text{cm}$ ), standards at both Emmaton and Jersey Point vary seasonally and with water year type. Standards are somewhat more stringent at Jersey Point in drier years (State Water Resources Control Board, 2000, Table 2).



SOURCE: Appendix C, Figure C.21.

NOTES: The figure shows the share of days exceeding the compliance limit for daily average EC during the irrigation season (April 1 through August 15). The results do not signify specific violations of standards because regulations are for a 14-day average

**Figure 4.8—Average Share of Days Above Regulatory Limits for Irrigation, with Sea Level Rise**

farmers on the San Joaquin River side (Jersey Point). With one foot of sea level rise, conditions in the western Delta deteriorate considerably, and with three feet, there is little difference among alternatives. All alternatives suggest that with sea level rise, irrigation in the western and southern parts of the Delta will become unsustainable in places that could not be connected to a peripheral canal.

## **Areas for Further Work**

The initial investigation undertaken here points to many areas that require more detailed modeling work regarding sea level rise, island flooding, and the effects of operational changes both now and in the future.

### ***Sea Level Rise***

There is some lack of agreement on whether tidal range changes with sea level rise will be accentuated or muted in the Delta by the San Francisco Bay. In particular, if Bay Area communities erect new levees to protect infrastructure and other assets from sea level rise (the most likely scenario), there would be a much stronger effect on the Delta than if the Bay were allowed to significantly expand its water surface area. Current models assume that the Bay geometry will remain unchanged. Expansion of the Bay's surface as a result of salt marsh restoration or abandonment of shoreline structures could lessen the effects of sea level rise on the Delta. Better data on water depths and Bay geometry are needed to analyze these effects.

### ***Island Flooding***

Although sea level rise will eventually increase salinity in the Delta with or without island failures, additional investigation is needed to assess the minimum number of western islands required to maintain current salinity levels until the effects of sea level rise become overwhelming. Investigations are also warranted to examine the effects of varying the locations and numbers of levee breaches. These issues challenge current modeling capabilities.



## ***Water Operations***

Explorations of changes in water quality regulations and operations for the new Delta will require much more in the way of hydrodynamic and operations studies than we were able to complete for this report. Model simulations also are needed to look beyond the static operations assumed in this analysis. Changes to upstream storage releases and reduced upstream diversions should be examined for different Delta export alternatives.<sup>9</sup> For instance, there is a need to understand the limits of canal capacity with more flexible operations of upstream reservoirs and downstream conveyance and storage capacity. Determining what volumes are feasible will depend not only on the implications of operational changes for salinity in the Delta but also on the consequences for the environment of reducing high flows on the Sacramento River below peripheral canal intakes. Operational changes also should be investigated in more detail to assess the extent of bi-directional flow changes with combined changes in operations, sea level rise, and island failures. As an example, one solution to the increased risks of bi-directional flow effects from an upstream intake may be to take water only on ebb tides, which would require greater canal capacity.

## **Conclusions**

This modeling exercise suggests that large changes are in store for Delta salinity as a result of natural forces acting on the Delta. Sea level rise will eventually increase Delta salinity beyond reasonable levels for drinking water and irrigation unless large increases in Delta inflows or reductions in exports are made. Permanently flooded western islands would have a similar effect, even if the islands are preflooded to avoid a “big gulp” associated with unexpected levee failures. In contrast, islands elsewhere in the Delta might be preflooded without long-term effects on Delta salinities provided the western islands remain intact. Modeling concurrent sea level rise and island flooding was not possible in the time available for this work. However, these two effects would at the very least be additive,

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<sup>9</sup> Some studies of statewide water operations and management are presented in Appendix F and could provide guidance to further hydrodynamic modeling.

making Delta water quality conditions difficult indeed for both urban and agricultural users.

Switching from the current through-Delta export pumping strategy to some form of peripheral canal or dual conveyance implies different outcomes for export water users and in-Delta water users. For export water users, a canal offers the possibility of blending in lower-salinity Sacramento River water. Even at current sea level, blending offers significant salinity improvements. A canal has different effects for in-Delta pumpers, depending on their location. Even when operated with minimum flow restrictions on the Sacramento River to prevent entrainment of aquatic life, a peripheral canal, operated in a dual conveyance mode, allows salinities to intrude farther up the Sacramento River, increasing salinity for Delta farmers in these areas. In contrast, salinities in the lower San Joaquin River and the western Delta generally decrease as less water is drawn into the Delta from the saltier Suisun Bay. A pure peripheral canal, without through-Delta exports, substantially increases salinity in the southern Delta, because fresher Sacramento River water is no longer drawn into the Delta from the Sacramento River to dilute San Joaquin River outflows. For southern Delta water users, this effect is similar to ending all exports. With sea level rise, the differences among different canal alternatives diminish.

Although today's Delta bears little resemblance to the lowland marshes of the Delta in pre-European times, the modeling also confirms that salinity would be more variable if it were not managed for through-Delta pumping. Active changes in water operations would be needed to return to more variable aquatic conditions—an important facet of rebuilding the Delta ecosystem, as described in the next chapter.

## 5. What a Changing Delta Means for the Ecosystem and Its Fishes

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“In the undisturbed state of a century ago about three-fifths of the delta was awash with an ordinary tide. Spring tides could submerge all of the backswamp. River floods were capable of overflowing the entire delta, particularly when crests, high tides, and westerly winds created a congestion above the outlet into Suisun Bay.”

*John Thompson (1957), The Settlement Geography of the Sacramento-San Joaquin Delta, California*

“The Delta ecosystem and a reliable water supply for California are the primary co-equal goals for a sustainable Delta.” This is the first recommendation in the long-term vision for the Delta suggested by the governor’s Blue Ribbon Task Force (Isenberg et al., 2008). A major challenge to achieving such a balance is that ecosystem water demands are neither straightforward to gauge nor constant across or within years. Simply allocating some fixed proportion of the water for ecosystem purposes is unlikely to recover populations of desirable species,<sup>1</sup> as evidenced by the failure of “environmental” water over the last decade or more to reverse endangered fish population declines. Owen (2007) points out that a key reason for this failure is that once a minimal allocation of water is made for environmental purposes, the rest is regarded as available for diversion, making it difficult to provide for the often unanticipated needs of fish. Moreover, evaluations of the beneficial effects of the amount or timing of water allocations for fish have rarely been adequate. This “managing by guessing” has a well-worn track record of failure (Ludwig et

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<sup>1</sup> We identify 17 of the Delta’s 46 fish species as “desirable” from a management perspective, meaning that they have at least two of the following attributes: They (a) are listed as threatened or endangered, or proposed for listing, under state or federal Endangered Species Acts; (b) support an important sport or commercial fishery; (c) are endemic or native; and (d) depend on the estuary to complete their life cycle, either by living there or migrating through it. The list of desirable species consists mostly of native, especially listed, species (delta smelt, green sturgeon, two runs of Chinook salmon, steelhead). The alien striped bass is also considered desirable because of its fishery and adaptations to estuarine conditions (see Appendix D for details).

al., 1993). In the Delta, it has resulted in a diminishing proportion of the water being made available for fish or ecosystem needs (except since 2007, when pumping was reduced to address the delta smelt crisis), and poor flexibility in how it can be used, a kind of nonadaptive management.

In this chapter, we address whether alternatives to the present through-Delta pumping strategy can make the Delta ecosystem more hospitable to desirable fish and other organisms.<sup>2</sup> We start by discussing the basic concepts and premises that must underlie any rebuilding of the Delta ecosystem and then assess the likely responses of key species to general export strategies. We conclude with a brief discussion of initiatives needed to make it possible to manage the Delta as a resilient ecosystem that maintains desirable characteristics, as it adjusts to natural and human-induced climatic variability. Background material for this chapter is found in Appendix D.

## Basic Premises for Rebuilding the Delta Ecosystem

The inevitable large-scale changes described in Chapter 2 will increase tidal open-water and marsh habitat area in the Delta and decrease the area devoted to agriculture and terrestrial habitat. Although the future configurations of the Delta and Suisun Marsh,<sup>3</sup> or rates at which they will change, cannot be predicted with complete accuracy, both areas will provide very different habitats for fish and wildlife than they do today, with a likely substantial increase in aquatic habitat. Thus, plans for ecosystem “restoration” must recognize that the new ecosystem will be very different from the present one as the result of changes as fundamental as those that transformed the Delta from marsh into farmland, towns, and roads in the past 150 years. This means that there is a unique opportunity to rebuild the ecosystem into one with attributes that society decides are desirable. By recognizing that the ecosystem will undergo major change with or without human intervention, it is possible to capitalize on the opportunity to

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<sup>2</sup> The Delta is just the upper part of the San Francisco Estuary but what occurs in the Delta affects the entire estuary. None of the desirable species are confined just to the Delta; most use other parts of the estuary as well. This chapter focuses on the Delta and Suisun Marsh, but it is important to keep the bigger picture in mind.

<sup>3</sup> In the rest of this chapter when we refer to the Delta, we also include Suisun Marsh because its fate and ecosystem are closely tied to those of the Delta proper.

determine the characteristics of the new ecosystem and assess how to tailor future configurations and management actions to promote these choices. The alternative—letting changes such as levee failures and invasions of harmful species occur haphazardly and hoping for the best—is very unlikely to satisfy anyone.

Ideally, ecosystem rebuilding will focus on creating habitat for species desired by society. However, many, perhaps most, species available to build the new ecosystem are alien species from all over the world that are already established in the Delta. Many of these alien species are regarded as undesirable (pests), whereas most remaining native species are regarded as desirable (as indicated by the listing of many as endangered species). One way or another, Californians will explicitly or implicitly make choices that affect the species that will dominate the new system by undertaking (or failing to undertake) actions related to physical structure, water management, fisheries, alien species, pollutants, and various other factors. Even though it is possible to promote desirable species, the rebuilt ecosystem will inevitably contain undesirable species as well, in an interacting mixture of native and nonnative species, as does the present system.

The likely changes in the Delta will potentially create habitats more favorable for desirable fish species than found in the present system, or at least unlikely to be worse. Moyle (2008) suggests that the increases in aquatic habitat caused by permanent flooding of the Delta's diked farmlands could be suitable for desirable native fish, such as delta smelt. These improvements should occur regardless of the water export alternative adopted, in part because conditions in the present Delta landscape are so unfavorable for many desirable species. Thus, if rebuilding the ecosystem is done deliberately, rather than by reacting to chance events, it is possible to tailor the environment to more often favor desirable species. The effectiveness of these actions also will depend on how well they discourage existing alien species that constrain ecosystem functions, particularly Brazilian waterweed (*Egeria densa*) and overbite clam (*Corbula amurensis*), and how well they prevent new invasions.

## The Role of Habitat Diversity

The key to promoting desirable aquatic species and maintaining them despite inevitable extreme episodes (i.e., prolonged drought or species invasions) is building heterogeneous habitats, such as tidal marshes, with a diversity of tidal and salinity conditions. This variability needs to take into account the physical, chemical, and biological requirements of the species at various stages in their life cycles and in different parts of the Delta.<sup>4</sup> Habitat diversity will not remove undesirable species, but it can disproportionately favor desirable ones, providing refuges in space and time that buffer groups of desirable species against adverse episodes. This idea is based on the concept of optimizing ecosystem resilience to avoid sudden shifts to undesirable dynamic states (Folke et al., 2004). It also draws on the principles of the Natural Flow Regime concept when managing regulated rivers (see Appendix D). Under this concept, flows are manipulated to favor native species (e.g., by providing spring spawning flows for native fish).

Because most future scenarios for the Delta entail a loss of terrestrial habitat, rebuilding the Delta should include improving terrestrial habitat quality on the fringes and less-subsided portions of the Delta and providing corridors to connect isolated patches. Such actions could actually increase habitat for the Delta's birds and other terrestrial species. The habitat likely to be lost to island flooding is largely marginal wildlife habitat associated with intensely farmed land; the biggest effects of its loss would be on overwintering species (e.g., sandhill cranes, waterfowl). Thus, rebuilding the Delta ecosystem presents an unusual opportunity to also create more wildlife-friendly agriculture and to improve existing areas for terrestrial species, especially those listed as threatened or endangered.

## Fish Species Responses to Water Export Strategies

The effect of water export strategies on Delta fish species has been a thorny question for more than half a century. Nevertheless, it is important to assess the likely effects of these strategies as California considers long-

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<sup>4</sup> This idea is presented in the "Eco-Delta" management alternative described in Lund et al. (2007).

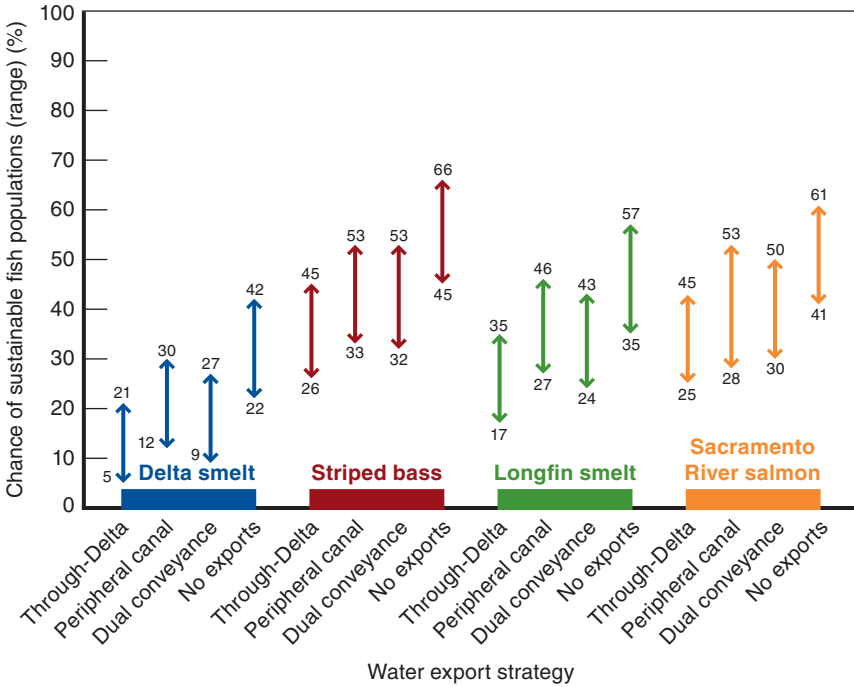
term management options for the Delta. Here, we examine the likely outcomes for desirable Delta fish of the four broad water export strategies described in Chapter 3: (1) continuing through-Delta pumping, (2) exporting water around the Delta with a peripheral canal, (3) using both through-Delta pumping and a peripheral canal (dual conveyance), and (4) ending water exports.

The problem is complex because exports are not the only major human influence; exports are imbedded in a system also influenced by the regulation of flow of the Sacramento River into the Delta from upstream dams and diversions, levee breaches, diversions by Delta farmers, clogging of channels by alien aquatic plants, various pollutants, and the operation of tidal gates and channels within the Delta. In the future, such complexity will be exacerbated by island flooding and other factors. Given these complexities and nuances, as well as the inevitable future surprises (such as new invasive species), we make qualitative comparisons of the likely performance of the four export alternatives based on

- the collective judgments of biologists and other Delta experts present at a February 2008 workshop;
- the groups of fish species (assemblages) that respond in similar ways to Delta conditions in time and space as shown by a multivariate analysis;
- the historical dynamics of key species and assemblages in relation to environmental variables as shown in an analysis of long-term trends;
- the major hydraulic factors that affect fish populations as the result of export strategies or other changes.

### ***Expert Judgments***

The results of a survey conducted at a workshop of the Estuarine Ecology Team in February 2008 captured the current thinking of 39 Delta aquatic ecosystem experts (primarily biologists with more than two years experience in working on Delta issues) about the future of key fish species (Appendix E). Most thought that declining species such as delta smelt and Chinook salmon would likely continue to decline, with some probability of extinction, regardless of the export path chosen. However, ending exports entirely was the option most likely to benefit these fishes (Figure 5.1).



SOURCE: Appendix E.

NOTES: The figure reports the averages of 39 experts' high and low estimates of fish population viability several decades into the future.

Figure 5.1—Expert Assessment of Likelihood of Sustainable Fish Populations in the Future with Different Water Export Strategies

Continuing only with through-Delta exports was considered the least beneficial, with dual conveyance and a peripheral canal essentially tied in an intermediate position. This general assessment agrees with our own.

### Fish Groupings

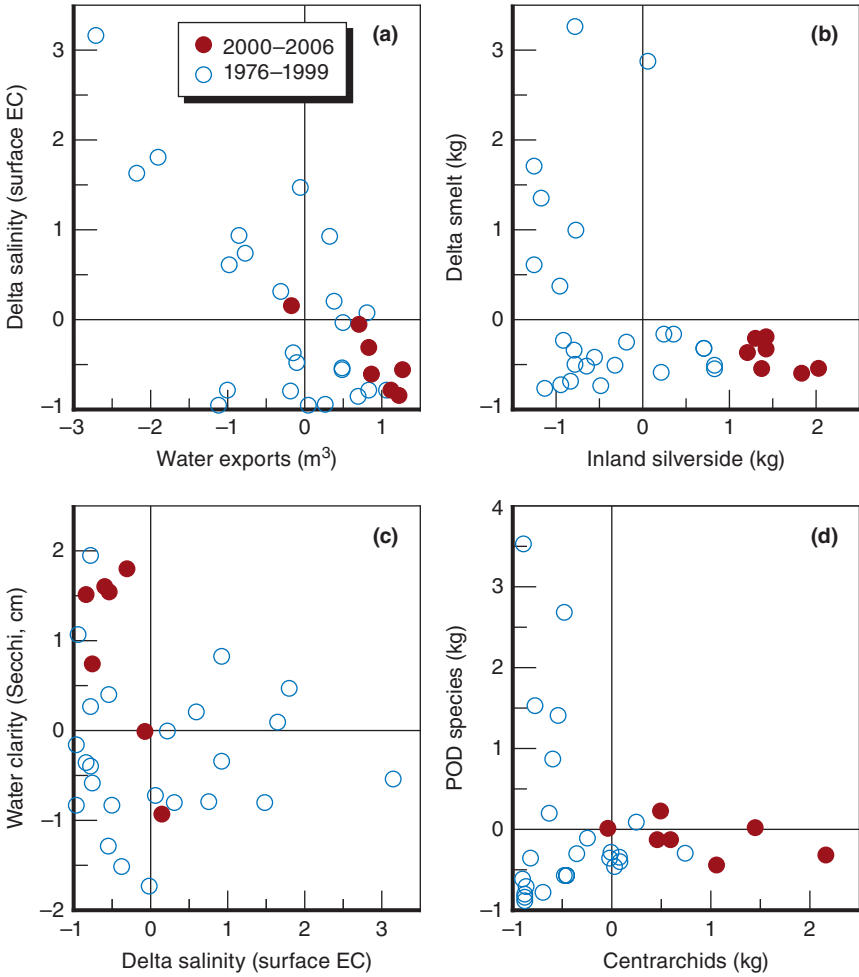
To assess whether groups of desirable fish species are likely to respond similarly to changing Delta conditions, we conducted a multivariate analysis (principal components analysis) to determine if Delta fish species fall into natural groups for management purposes (Appendix D). Five such groups were identified: (1) the “smelt” group (desirable)—the short-lived pelagic species delta smelt and longfin smelt; (2) the “anadromous” group



(desirable)—striped bass, American shad, Chinook salmon, plus brackish-water benthic species (those that live and forage on or near the bottom), including staghorn sculpin, starry flounder; (3) the “freshwater benthic” group (desirable)—mostly native species (splittail, Sacramento sucker, prickly sculpin, tule perch) plus the nonnative mosquitofish and shimofuri goby; (4) the “Delta freshwater planktivores” group—threadfin shad, inland silverside, hitch; (5) the “slough-resident fish” group, which includes the centrarchids—mostly nonnative species associated with beds of aquatic vegetation, including largemouth bass, bluegill sunfish, bigscale logperch, common carp, white catfish. Most fish in the last two groups either have negative interactions with desirable Delta fish by competing for food and habitat or do well in the areas infested with waterweed that are avoided by most desirable fish. The results of this analysis suggest that the Delta can be managed to favor groups of desirable species, as discussed further below.

### ***Species Dynamics and Ecosystem Regime Shift***

To assess how key species and assemblages have responded to changing Delta conditions over the past 40 years, we conducted an analysis of trends in several key variables, including water exports, salinity, water clarity, and the biomass of key native and alien species (a measure of fish abundance) (Appendix D). Figure 5.2 presents these data in phase plots, which depict the results for each variable relative to its long-term average (set to zero) for each year from 1976 to 2006. The most recent years (2000 to 2006) are depicted by solid red dots and earlier years by hollow blue dots. In general, the analysis shows that there was more variation from the long-term average in years before 2000. The reduced variation in recent years indicates a broad shift toward undesirable environmental conditions. As water exports have increased, the variability in Delta salinity has decreased (panel A), maintaining lake-like conditions favored by invasive Brazilian waterweed, which in turn creates conditions that favor undesirable species (mostly the slough-resident fishes, described above) and that are unfavorable for desirable native species. As an abundance of inland silverside (a potential alien predator and competitor with delta smelt) has increased, the biomass of delta smelt has become consistently small (panel B). As salinity has become less variable, water clarity has increased (as a result of declining sediment input from rivers and an increase in pond weed abundance)



SOURCE: Appendix D. Data are from July–September 1976–2006.  
 NOTE: Data are plotted with zero mean and unit standard deviation.

Figure 5.2—Regime Shift in the Delta Ecosystem

(panel C), providing less favorable habitat for desirable fish species. As alien centrarchid fishes (largemouth bass and bluegill sunfish) have become more abundant, the biomass of native smelt and striped bass (“POD” or “pelagic organism decline” species) has become smaller and less variable (panel D).

The decline in variability of these conditions since 2000 suggests that the Delta has entered a new ecological regime.

This analysis leads us to conclude that the Delta ecosystem has shifted toward a regime of reduced environmental variability, especially in salinity and water clarity. Essentially, the Delta ecosystem has shifted over the past decade from a regime favoring delta smelt and other native species to one favoring undesirable alien fishes.

Shifts to new regimes are thought to be triggered by the interactions between “slow” and “fast” processes once some critical threshold is exceeded (Scheffer and Carpenter, 2003). The long-term rising trend in water exports (a slow process) has constrained the natural variability in flows and other environmental conditions, facilitating the proliferation of alien species, including invasion of new species (a fast process). The interrelationship of these processes appears to have tipped the system dynamics since the early 2000s. The low variability in recent years, potentially enhanced by the habitat-stabilizing properties of Brazilian waterweed and the long life span of the predatory largemouth bass, suggests that it will be hard to push the ecosystem back to a regime favoring desirable species without significantly altering Delta water management.

### ***Hydraulic Effects on Delta Fishes***

Major changes in hydraulic factors that can affect Delta fish species include (a) changes in inflows, particularly from the Sacramento River, (b) increased flooding of Delta islands, (c) changes in the movement of water across the Delta, (d) salinity intrusion in the western Delta, (e) dilution of pollutants (e. g., ammonium, pesticides) entering the Delta, particularly agricultural drainage from the San Joaquin River, (f) changes in the total volume of through-Delta pumping, and (g) changes in amount of water diverted upstream of the Delta, particularly with a new intake for exports on the Sacramento River. The four export management alternatives will affect these factors differently. One way to look at how the alternatives affect the hydraulic environment for fish is to score each one according to its likely positive and negative effects on fish. Table 5.1 presents such a ranking, drawing largely on our own professional judgment while taking into consideration the opinions of experts surveyed at the February 2008 workshop (Appendix E, Tables E.3 and E.4).

**Table 5.1**  
**Estimated Effects of Export Strategies on Major Hydraulic Factors and Delta Fishes in the Next 50 Years**

Factor	Through-Delta Pumping		Peripheral Canal		Dual Conveyance		No Exports	
	Effect on Factor	Effect on Fish	Effect on Factor	Effect on Fish	Effect on Factor	Effect on Fish	Effect on Factor	Effect on Fish
Sacramento River inflow	0	0	-2	-	-1	-	2	+
Island flooding	-1	-	2	+	-1	-	2	+
Across-Delta flow	2	-	-2	+	-1	+	-2	+
Salinity intrusion	-2	-	2	+	-1	-	2	+
San Joaquin drainage water	1	-	2	-	1	-	1	-
Pumping through Delta	2	-	-2	+	-1	+	-2	+
Export intake on Sacramento River	0	0	2	-	1	-	0	0

SOURCE: Authors' estimates, assisted by expert survey results (Appendix E).

NOTES: The effects on factor are measured on a five-point scale: -2 indicates a major decrease in the effect of a factor, -1 indicates a moderate decrease, 0 indicates no change or a very small decrease from today's conditions, 1 indicates a moderate increase, and 2 indicates a major increase. The effects on fish are measured as the probable directions of effects on desirable fish species: "+" (positive), "-" (negative), and "0" (no change). Thus, the export strategy of through-Delta pumping has a score of 2 on "Pumping through Delta" indicating that this export strategy has major effects on Delta water flow patterns through the effects of the pumps, and a score of -2 on "Salinity intrusion" indicates that this export strategy would maintain low salinity in the Delta and in exported water. Both factors would have negative effects on desirable fish.

These results suggest that ending Delta exports is best for estuarine fish because it would allow the resumption of more natural estuarine flow patterns, assuming that there is no major increase in the amount of water diverted upstream in the Sacramento Valley. If hydraulic conditions remain roughly the same as today, then through-Delta pumping clearly has major effects on Delta flow patterns, with harm to desirable fish

species, including by entrainment. The likely effects of a peripheral canal on fish are strong but mixed. Although a canal largely eliminates the negative effects of through-Delta pumping, the large diversions on the lower Sacramento River would reduce inflows to the Delta and might have major effects on salmon and other fish that swim upriver. It is also unclear whether fish that live in the Delta would be harmed by the greater influence of San Joaquin River water, with its warmer temperatures and high salt and pollutant levels, or whether higher nutrient inputs from this water would stimulate Delta food webs and eventually benefit desirable species. Ecosystem function would depend largely on the amount and timing of Sacramento River water allowed into the Delta, as well as on the extent of island flooding. Dual conveyance retains the generally negative effects of through-Delta pumping, but these disadvantages could be ameliorated somewhat by the more opportunistic pumping afforded by dual intakes.

Because some of these hydraulic influences affect different fish differently, it is useful to consider the likely effects of the export strategies on each of the five groupings of Delta fish species identified above (Table 5.2).

Continuing through-Delta pumping would be generally bad for the three groupings of primarily desirable fishes. Because the status quo has demonstrably negative effects on desirable fish species, it is unlikely that

**Table 5.2**

**Potential Effects of Water Export Strategies on the Five Groupings of Delta Fishes**

Fish Species Group	Through-Delta Pumping	Peripheral Canal	Dual Conveyance	No Exports
Smelt (desirable)	-2	1	-1	2
Anadromous (desirable)	-1	-2	-1	1
Freshwater benthic (desirable)	0	1	1	1
Delta freshwater planktivores	0	0	0	1
Slough-resident fishes	2	1	1	0

NOTES: Effects are measured on a five-point scale: -2 = strong negative change from present conditions (decrease in distribution and abundance), -1 = moderate negative effect, 0 = no effect or small effect, 1 = moderate positive effect, and 2 = strong positive effect.

just tinkering with operations of this water delivery system will make things much better.

Relying entirely on the peripheral canal for water exports might be better than the present system for pelagic fishes such as delta smelt and longfin smelt. The two most compelling drawbacks are (1) the eggs and larvae of striped bass and American shad may face increased entrainment from an upstream intake, and (2) juvenile Chinook salmon may encounter entrainment problems with the intake and increased water quality problems on the San Joaquin River side of the Delta. A canal could be designed and operated to greatly reduce these threats to fish by better aligning the timing and amounts of water entering the Delta to foster desirable ecosystem attributes. In this case, the score of a canal option would improve in Tables 5.1 and 5.2.

The dual conveyance option has the potential for more flexible management than does a pure peripheral canal (Chapter 3). Although dual conveyance in theory could reduce the negative effects on desirable fishes by allowing switching between the two intakes, it could also be operated in ways that combine the negative effects of both the peripheral canal and through-Delta pumping. Dual conveyance would need to be operated carefully to avoid direct entrainment effects and dramatic reductions of fresh water inflows to the Delta.

The no exports option would have generally positive effects on all three groups of desirable fishes. Although it may be unrealistic to implement this alternative because of costs to human water users, consideration of this alternative from an ecosystem perspective provides a model for creating better conditions for desirable fish species. However, even this option can have its positive effects negated by invasions of new alien species with ecosystem-altering properties, as has happened in the recent past with overbite clam and Brazilian waterweed.

### ***Working with Uncertainties***

The results of these comparative analyses of the export options, although crude, indicate the difficulties of exporting large amounts of water from the Delta in a way that is compatible with fish conservation and the rebuilding of an ecosystem with many desirable attributes. If an improved Delta environment is to be coequal with water exports as a societal goal,

then a major effort must be made to create that environment by working *with* the inevitable large-scale changes, rather than fighting them, or ignoring them (only to lose). There must be enough flexibility with diversions and inflows to reduce direct entrainment effects on fish species and allow for variable environmental demands.

The projected large-scale changes to the Delta will irreversibly alter the state of the system. The new Delta can have attributes that favor desirable fishes (and other organisms), such as maintaining Suisun Marsh as a tidal brackish system, open-water habitat relatively free of overbite clam, Brazilian waterweed, and other invasive species, with a more natural tidal and inflow pattern. However, creating an ecosystem with desirable attributes first requires societal recognition that humans benefit from the ecosystem services provided by this highly altered system.<sup>5</sup> Only then can resiliency to future change be built into the new system by future managers (Scheffer et al., 2001; Folke et al., 2004; Walker and Salt, 2006).

Unfortunately, not all aspects of the inevitable large-scale change can be ameliorated by new management practices. The rise in temperature of the freshwater inflow as the result of climate change is particularly worrisome because it will increase the stress on native fish species, especially delta smelt. Delta smelt survival in the face of this change would be possible if the species can adapt to the changing temperature regime or if the inevitable increase in river temperatures will be countered by intrusion of cooler tidal waters and ensuing changes in estuarine hydrodynamics. At this point, scientists do not know whether either pathway is likely.

## Attributes of an Ecosystem Solution

To tackle the problems of the Delta, it is always important to keep in mind that the rebuilt ecosystem will contain constituents and characteristics far removed from those that existed previously. The historic Delta was unique in its characteristics, as will be the future Delta, with only superficial resemblance to current and past Deltas. If exports and environment are to be coequal, it will be necessary to work to systematically foster favorable ecosystem attributes, while recognizing that human control over natural events is quite limited. Below, we describe some potential

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<sup>5</sup> This concept is known as “reconciliation ecology” (Rosenzweig, 2002).

actions to achieve this type of ecosystem solution, presented as examples to guide solution-oriented thinking. Figure 5.3 provides an illustration of what an eco-friendly Delta might look like in the future.

### ***Planning and Regulation***

- Develop a coordinated, systemwide vision and plan for ecosystem rebuilding, with management decisions guided by large-scale environmental manipulation (i.e., adaptive management).
- Develop an aggressive regulatory system to help prevent new invasions of alien species along with tools to react quickly to eradicate newly established aliens, to prevent unpleasant surprises created by invaders that change ecosystem attributes (as Brazilian waterweed and overbite clam have done in the past decade).

### ***Experimentation***

- Conduct large-scale environmental experiments to learn how to better manage the new Delta's habitats. The suitability of the new open-water habitats for desirable species will depend in part on the responses of harmful invasive species, including overbite clam and Brazilian waterweed, to the changed system. A proactive experimental approach is required to guide the evolution of habitat in these flooded areas, which will be larger and deeper than the currently flooded islands (e.g., Franks Tract) and are poor models for the future landscape. Potential experiments include (1) flooding one island while monitoring closely the effects on aquatic organisms and water quality, (2) constructing a gated, floodable island on the Delta Wetlands model that can be used to experiment with different flooding, salinity, and temperature regimes,<sup>6</sup> and (3) testing large-scale programs to reduce populations of alien species that are ecosystem engineers (e.g., removal of overbite clam by dredging).

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<sup>6</sup> The Delta Wetlands project is a proposal to use two islands in the central Delta as freshwater storage facilities and two others as waterfowl habitat. The model proposes building wide levees that slope toward the interior, supporting riparian vegetation and interior water levels.



## *Toxicants*

- Reduce pollutants, especially ammonium and pesticides, from regional agriculture and urban areas through education, incentives, better regulation, land retirement, and cap-and-trade systems for limiting and allocating pollution loads.<sup>7</sup>
- Reduce or eliminate input of salts, warm water, and toxic pollutants to the southern Delta from the lower San Joaquin River.

## *Flow Patterns*

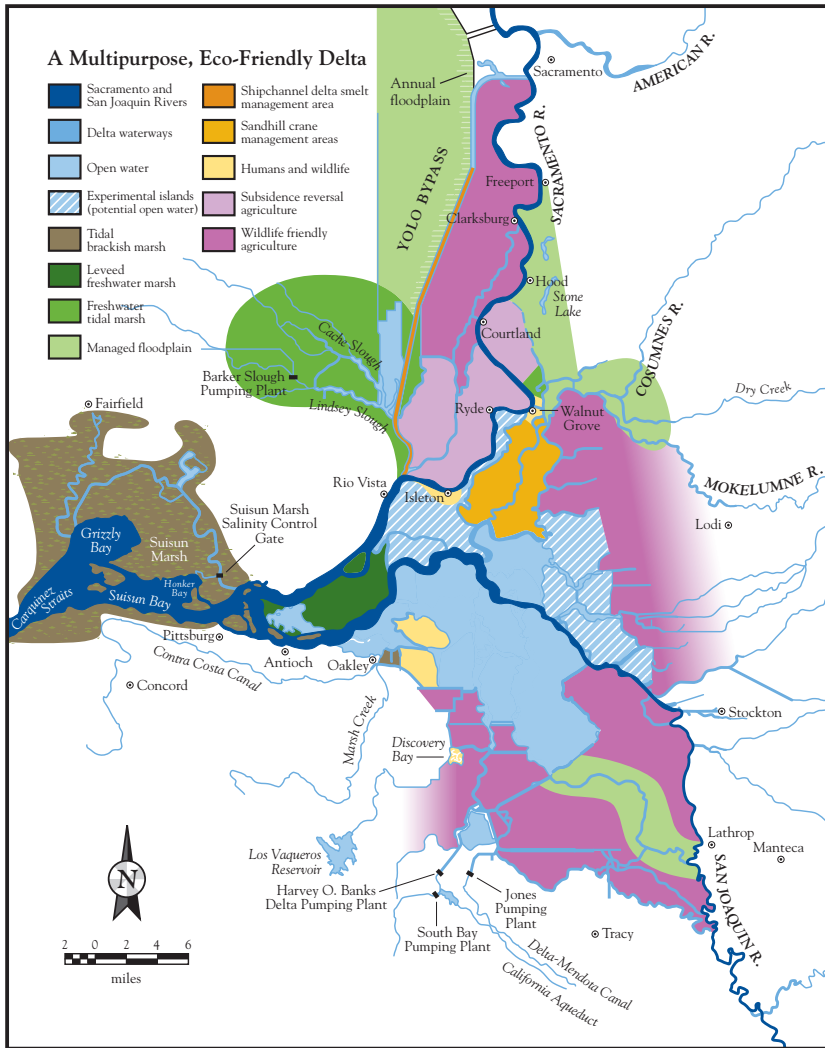
- Create a Delta inflow pattern flexible enough to adjust to changes in physical ecosystem structure (e.g., island flooding) while providing the flows needed for desirable species to successfully complete their life histories (e.g., for spawning of delta smelt).

## *Habitat Restoration*

- Create diverse, native fish-friendly tidal habitats on the peripheries of the Delta, especially in the Cache Slough region and Cosumnes River.
- Recognize that much of Suisun Marsh will become subtidal and tidal brackish water habitat as the result of sea level rise, but try to direct the change through management of levees and areas most likely to flood soon.
- Improve the Yolo Bypass as a fish habitat, especially through the annual flooding of some areas; create a similar bypass on the San Joaquin side (e.g., on Stewart Tract).
- Create large blocks of upland habitat on the margins of the Delta and create corridors to connect isolated patches of habitat, to favor terrestrial species, especially overwintering birds. Much of this land could be devoted to wildlife-friendly agriculture.

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<sup>7</sup> “Cap-and-trade” refers to a regulatory approach in which a total cap on pollutants is established and polluters are then allowed to trade amongst themselves to determine the actual allocation of the total pollution load. This method can allow pollution reductions to be achieved at a lower overall cost than blanket restrictions on pollutants.



NOTES: The key aspects of this map include: (1) protecting levees in the western Delta to allow for at least opportunistic through-Delta pumping; (2) large expanses of pelagic, open water habitat; (3) large areas maintained for environmentally friendly agriculture; (4) Suisun Marsh recreated as a brackish water tidal marsh; (5) large areas of freshwater tidal marsh; (6) the Sacramento ship channel and deep areas of Cache Slough managed for delta smelt spawning; (7) large expanses of floodplain, with annual floodplain created along the eastern edge of the Yolo Bypass; (8) the Stockton ship channel maintained through a larger area of open water (shown here as the San Joaquin River); (9) the integrity of the Sacramento River maintained through the Delta for salmon migration; and (10) islands reserved for experimental use, including flooding.

Figure 5.3—Land and Water Use in an Eco-Friendly Future Delta

## Conclusions

This assessment of the long-term prospects for the Delta ecosystem and its fishes leads to five main conclusions.

First, large-scale ecosystem change is inevitable in the Delta and the new ecosystem will be very different from both the historic and the present ecosystems. Key aspects of the new ecosystem will be large areas of open-water habitat and greater heterogeneity in environmental conditions, especially salinity.

Second, a general factor associated with the decline of desirable fish species in the Delta in the past two to three decades has been a trend for the environment to become a less heterogeneous, more freshwater-dominated system. The low variability in summer water quality, potentially enhanced by the habitat-stabilizing properties of Brazilian waterweed and the long life spans of some alien fishes, suggests that it will be hard to push the ecosystem back to a regime favoring desirable species without significantly altering Delta water management.

Third, different groups of fish species are favored by different sets of environmental conditions, indicating that general management strategies can be established to benefit groups of desirable species (e.g., pelagic and anadromous species). However, the benefits of any management strategy can be greatly reduced by the invasions of new alien species.

Fourth, the best water export strategy to favor desirable fishes is to end exports, assuming that upstream diversions do not increase substantially. The worst strategy is to keep pumping large amounts of water through the Delta. Any export strategy (including ending exports) must include a large component of restoring habitat diversity and function throughout the Delta and Suisun Marsh if it is to be successful at bringing back large populations of desirable fish species.

Fifth, because of high uncertainties as to how ecosystem change will affect desirable species, large-scale *in situ* experiments are needed (e.g., flooding islands) to find management strategies that have the highest likelihood of success. In addition, several large-scale restoration projects identified here (Cache Slough, Suisun Marsh, and Yolo Bypass) are very likely to benefit many desirable species.



# 6. Economics of Changing Water Supply and Quality

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“All models are wrong, but some are useful.”

*George E. P. Box (1987), Empirical Model-Building and Response Surfaces*

The Delta is a major source of water for urban and agricultural uses in the Bay Area, the southern Central Valley, Southern California, and the Delta itself. The recent rise of water markets has more closely linked water management in upstream and importing regions of the state, and the evolving natural conditions in the Delta and modifications in export management policies will cause major changes for water users and managers throughout California. In this chapter, we estimate the costs of different approaches to managing Delta exports and outflows from the perspectives of both water supply and quality. Although there is substantial expertise and knowledge of these costs at the local and regional levels, this knowledge has not been well-integrated. We provide an initial attempt to synthesize these costs from a statewide perspective. Our estimates are not exact, but they form a reasonable basis for drawing some broad conclusions about the economic implications of different export alternatives.

## Costs of Providing More Water for the Environment

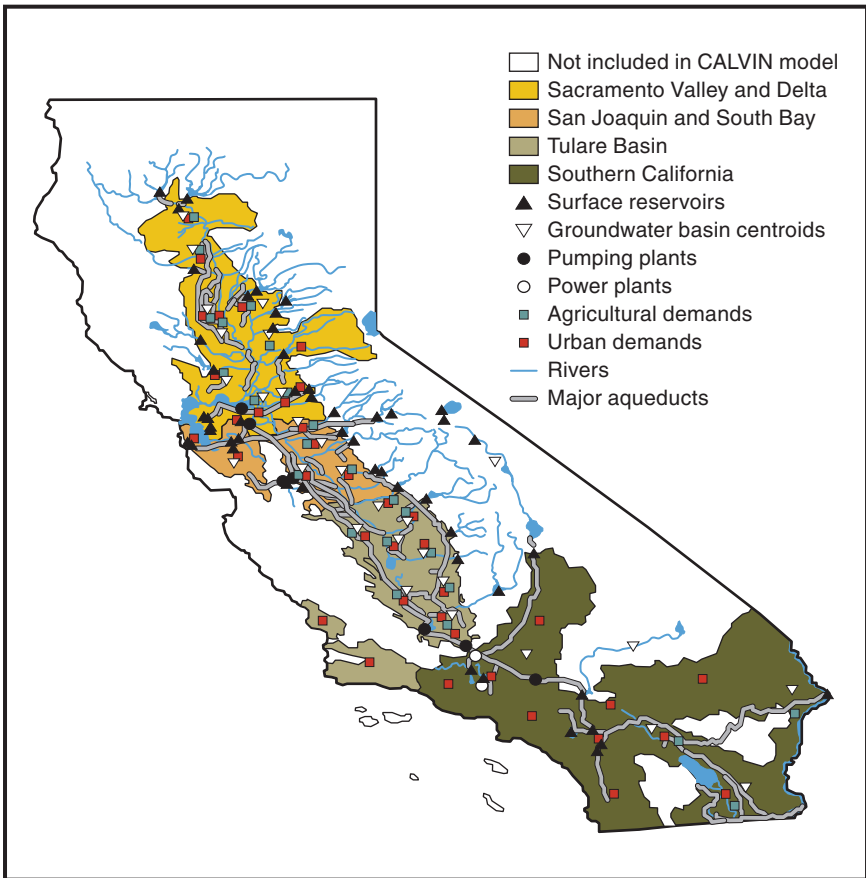
Under the present through-Delta pumping system, water exports from the Delta raise two major environmental concerns: (a) entrainment of fish and disruptions of fish movement by the export pumps in the southern Delta, and (b) the volume and timing of net fresh water outflows from the Delta to the sea, which affect the location, extent, and variability of habitats available to various species through the course of their life stages (Chapter 5). Both issues are affected by the quantities of water exported from the Delta, as well as by a host of other aspects of internal Delta water management and water export characteristics, such as location of exports, operating pattern, and specific design of facilities. Net outflows from the Delta also are affected by the volume of upstream diversions,

which are nearly twice as large as volumes exported from within the Delta (Chapter 3).

For several decades, exports have been regulated in various ways to protect fish and Delta agriculture and urban uses, most notably with minimum flow requirements and maximum salinity standards at particular times of the year. Judge Wanger's ruling in late 2007 has led to further restrictions on export pumping to reduce the risk of entrainment of delta smelt (Chapter 1). Other recent discussions suggest the potential for additional regulatory actions. In light of fish population declines, both the Delta Vision Blue Ribbon Task Force (Isenberg et al., 2008) and many environmental advocates have argued for considering a future with reduced exports, with export users relying more on local supplies and conservation. The Task Force also indicated that upstream water users should contribute by limiting their use of the waters flowing into the Delta.

A major policy question is how the potential reductions in export levels and upstream diversions would affect individual water users and the wider economy. Water users have many ways to adjust to cutbacks, each of which entails some costs. Water users throughout California's main population centers and farming regions are tied to an extensive water storage and conveyance system, including groundwater and surface water storage, canals, pipelines, pumps, hydropower turbines, and water and wastewater treatment plants (Figure 6.1). Local supplies can also be expanded through treatment of wastewater, construction of desalination facilities, and new conveyance and storage, and water users can also manage their own water demands (through conservation and rationing) or buy water from others who have lower-valued water uses. In short, water users have considerable ability to adapt to changes in how the Delta is operated. Some adaptations are likely to be more costly than others, presenting higher operating costs or imposing greater water scarcity (or shortage)—lost profit for farmers and greater expenses and inconvenience for urban users.

To take into account the many options for adapting to changes in water availability, it is necessary to use a computer model of the California water system. Here, we used the CALVIN (California Value Integrated



NOTE: The figure shows the water system represented in the CALVIN model, discussed in the text. Areas shown in white have localized water systems, not highly connected to the statewide system.

**Figure 6.1—California’s Statewide Water Supply Network**

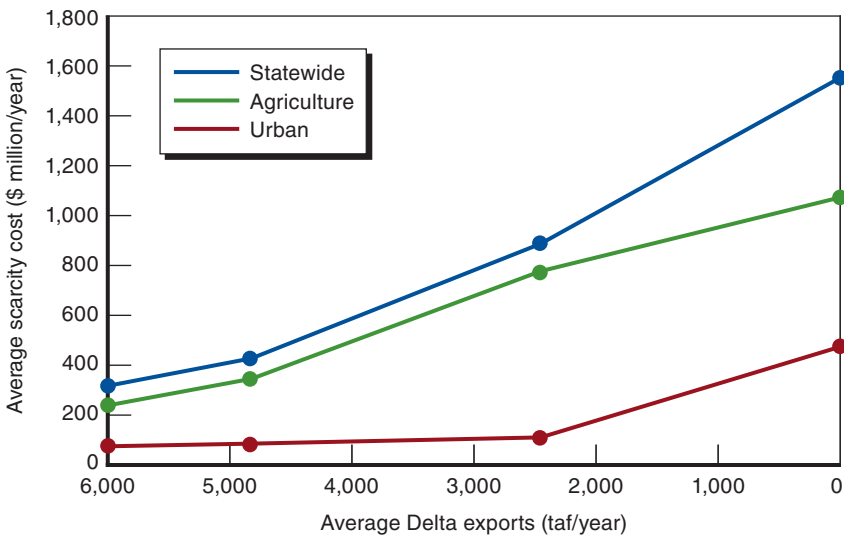
Network) model of California’s statewide water supply system.<sup>1</sup> This model suggests economically promising portfolios of water management

<sup>1</sup> The CALVIN model has been widely applied to provide insights for a variety of California water problems (Draper et al., 2003), including climate change with substantial population increases (Tanaka et al., 2006; Medellin et al., 2008), water markets (Jenkins et al., 2004), conjunctive use (Pulido-Velázquez, Jenkins, and Lund, 2004), Hetch Hetchy dam removal (Null and Lund, 2006), and earlier Delta policy studies (Tanaka et al. 2003; Lund et al., 2007).

activities in response to a set of economic, population, climate, policy, and infrastructure conditions. Because we are interested in assessing how water users would adapt to long-term changes in Delta policy, we examined scenarios with population and land use conditions at the middle of this century (2050). Details of the results appear in Appendix F.

### Reducing or Ending Water Exports

Figure 6.2 depicts the statewide costs of water scarcity (or shortages) from a planned reduction in water export volumes, starting from a 2050 baseline demand of approximately six million acre-feet and declining to no exports whatsoever. Even at this baseline level, water users experience some water scarcity costs—on the order of \$300 million per year statewide. Costs of initial cutbacks are relatively small, but they rise significantly for the agricultural sector once exports are reduced by more than one million acre-feet. The urban sector begins to experience significant scarcity only when exports are restricted to less than half their initial volume. Cities would avoid the full brunt of cutbacks by purchasing water from southern Central Valley farmers who currently use local inflows and employing



SOURCE: Appendix F.

Figure 6.2—Annual Average Statewide Scarcity Costs, with Changing Export Restrictions, 2050



more wastewater reuse, seawater desalination, and water conservation. Although cities would face higher water prices as a result of these shifts, southern Central Valley agriculture would see the greatest overall effects from the cutbacks, from the loss of water supply and, for some, from selling available water to Southern California urban users. Individual farmers who were able to sell water could experience financial gains, but the local communities would experience a loss in economic activity related to farming, as described below.

When additional net operating costs of roughly \$200 million are added to these water scarcity cost estimates, a planned ending of Delta exports is estimated to cost the statewide economy roughly \$1.5 billion per year (2008 dollars). Because this cost estimate is based on modeling that assumes that water managers have perfect knowledge about future hydrologic conditions and face no institutional constraints to water marketing, the real costs would likely be higher. For instance, if farmers elected not to sell more water to urban areas once exports were ended, the total cost to the economy would jump to \$2.2 billion, as urban water users adopted higher-cost sources. Allowing for other inefficiencies and delays, the upper bound on statewide costs of ending exports might be as high as \$2.5 billion.

Small reductions in exports are significantly less costly because there is the possibility of reallocating water from lower-valued (mostly agricultural) uses, through the water market (including transfers from lower-value to higher-value farming—as often occurs today (Hanak, 2003)). Even for large reductions or elimination of water exports, the economic costs, although large, are not catastrophic for California's \$1.7 trillion per year statewide economy. Planning for such a transition significantly lowers costs. By way of comparison, an unplanned, temporary interruption of exports from a catastrophic failure of the Delta levees is estimated to cost water users from \$8 billion to \$15 billion (URS Corporation and Jack R. Benjamin and Associates, 2007b).

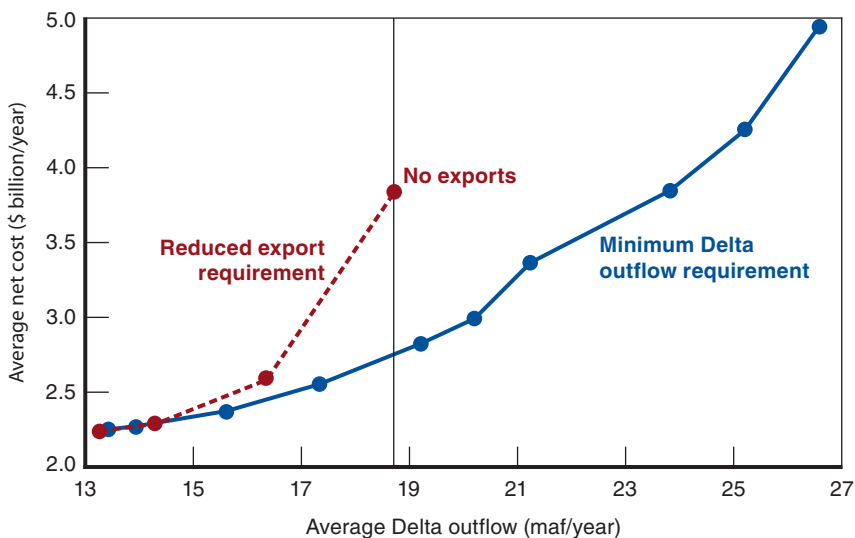
Seen from another perspective, our estimate of total economic costs of ending Delta exports can mask the social consequences for specific regions. In particular, this estimate measures losses to the southern Central Valley agricultural sector in terms of forgone returns to land and farm management when land is taken out of production—a loss of roughly \$800 million. But the cutbacks in water (–29%) and acreage (877,000

acres, or 26%) imply a substantially greater loss in regional revenues and employment. Farm revenues would drop by \$3.3 billion (–17%), regional revenues by \$4.4 billion, and regional employment by over 100,000 jobs (Appendix F). These results highlight the disproportional effect of ending exports on the southern Central Valley.

### ***Increasing Net Delta Outflows***

Under the current system, where exports are drawn through Delta channels to the pumps, directly reducing exports could avoid or lessen entrainment and other problems created by altered flows within the Delta. If, instead, exports are diverted around the Delta through a peripheral canal, the pumps no longer play a direct role in the Delta, and the regulatory issue is mainly one of maintaining appropriate flows into and out of the Delta. Increased net Delta outflows also could be sought to maintain salinity standards for agricultural and urban users within the Delta in the face of sea level rise, which is likely to draw salts from the ocean and Bay further into the Delta (Chapter 4).

Restrictions on water exports can increase net Delta outflows by reducing the amount of water diverted from the system. However, the goal of increasing outflows can be attained more directly (and cost-effectively) by regulations requiring increased outflows (Figure 6.3). Even if export users have the regulatory responsibility to ensure that such flow requirements are met (as is currently the case), outflow requirements allow more senior upstream diverters to participate in the solution by leasing or selling some of their water to export users. Figure 6.3 compares the costs of increasing Delta outflows for these two regulatory approaches. The burgundy-colored curve shows the costs of using reduced export requirements. At the left-hand end of the curve, annual export levels are roughly six maf and average net Delta outflows are roughly 13 maf. When the restrictions reach their maximum level, with zero exports (the right-hand end of the “reduced export requirement” curve), average net Delta outflows are 18.7 maf per year. It would be possible to achieve the same volume of outflows with a direct outflow requirement (the blue curve) at a significantly lower cost to the economy: \$1.1 billion per year lower.



SOURCE: Appendix F.

NOTE: The reduced export requirement curve shows the average Delta outflows with exports ranging from recent levels (around six maf/year) to zero.

Figure 6.3—Statewide Costs of Alternative Regulations for Delta Outflows, 2050

### *The Value of New Infrastructure*

We also used the CALVIN model to estimate the economic value of expanding water management facilities, such as surface storage and conveyance, under these regulatory alternatives. If water exports were substantially restricted or ended, it would be quite valuable to expand some local and regional conveyance facilities and add more interconnections among existing facilities. Such investments would increase the capacity of water users to transfer water and to benefit from regional investments in new supplies. In contrast, additional water storage rarely looks economically promising under these reduced export scenarios. Exceptions include additional groundwater recharge in the Bay Area and Southern California and local surface storage in Southern California (Appendix F). Similar patterns emerge when net Delta outflow requirements are increased.

## Urban and Agricultural Water Quality

The increasing salinity of Delta water with sea level rise and island flooding raises questions about the economic costs of different export management alternatives from various quality perspectives. Here we summarize estimates of the effects of Delta water quality on drinking water treatment costs—an important consideration for the many urban users of Delta waters—and on agricultural revenues in the southern Central Valley.

### *Drinking Water Treatment Costs*

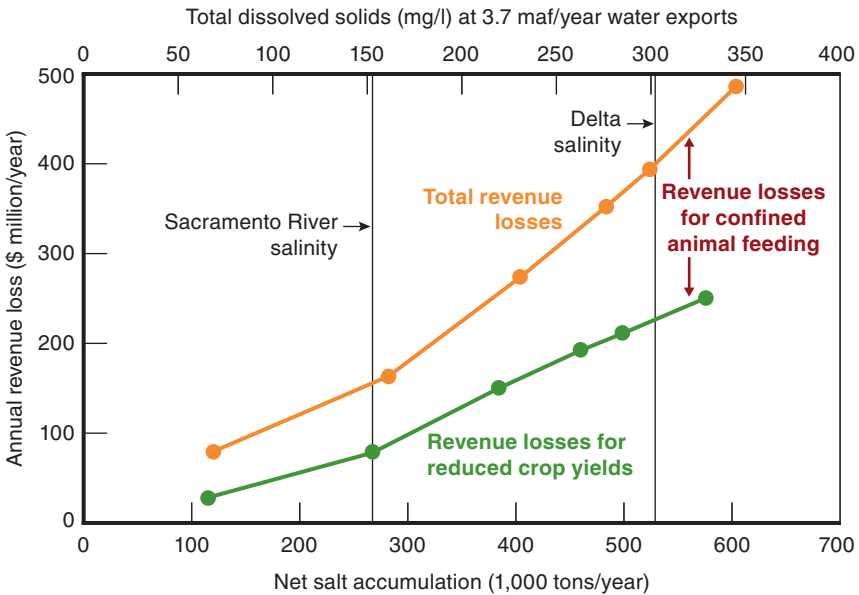
Salts and organic compounds present in Delta waters increase drinking water treatment costs and health risks for urban users in the Bay Area and Southern California. Under today's conditions, the Delta already has significantly lower quality water than upstream locations on the Sacramento River, where intakes to a peripheral canal would be located. We estimate that the costs of treating drinking water from the Delta are currently \$20 to \$60 per acre-foot higher than if water were taken upstream of the Delta from the Sacramento River. (See Appendix H for details.) With sea level rise or western island flooding, the additional cost of using the Delta as a source of urban water supply would rise to \$100 to \$500 per acre-foot. The deteriorating quality of Delta water also raises cancer risks from ingestion of disinfectant byproducts, which are not normally removed during treatment.

### *Agricultural Losses*

Until recently, 3.7 maf per year of water were exported on average from the Delta to agricultural water users in the southern Central Valley. These exports also delivered 1.5 million tons of salt (at 300 mg/l) per year, resulting in approximately 500,000 tons of net salt accumulation in these agricultural lands (Orlob, 1991; Shoups, 2004). The accumulation of salts is steadily degrading the productivity of agriculture in parts of the southern Central Valley, particularly on the western side. Salinity lowers crop yields,

prevents the farming of some higher-value crops, and can ultimately render land unprofitable for agriculture. Salinity also constrains confined animal feeding operations, because it limits where animal wastes can be applied.<sup>2</sup>

If this region continues to experience recent levels of water exports at current levels of Delta salinity (3.7 maf/year at 300 mg/l) and farmland salinization continues at past rates, additional losses of agricultural revenues resulting from salinity could reach \$392 million per year by 2030 (Figure 6.4). This salinity cost will average about \$105 per acre-foot of water delivered, with a marginal cost of roughly \$135 per acre-foot.<sup>3</sup> Reducing export salinity to the levels in the Sacramento River (150 mg/l) might



SOURCE: Appendix I.

**Figure 6.4—Agricultural Revenue Losses from Annual Salt Accumulation in the Southern Central Valley, 2030**

<sup>2</sup> Confined animal feeding operations (dairies, cattle, etc.) in the Central Valley often use animal wastewater to fertilize feed crops. Salts in wastewater combined with salts in irrigation and groundwater can reduce the allowable rates of wastewater application to the land, which in turn can limit the number of animals that can be supported on a given area of land.

<sup>3</sup> These calculations assume that agricultural drainage is reduced in proportion to the imported salt load.

lower these costs by as much as \$241 million per year (Figure 6.4) or \$65 per acre-foot of water delivered. These water quality benefits will be lower if current trends in the growth of shallow saline areas do not continue or if reduced salt loads do not slow the growth of salt-affected areas. Taking into account these factors, salinity costs to agriculture from using Delta water rather than Sacramento River water appear to lie in the range of \$210 million to \$270 million per year (Appendix I). Although these estimates are preliminary, they suggest that as salts accumulate, the salinity costs to southern Central Valley agriculture are substantial and will grow with time. Indeed, these estimates may be conservative insofar as they assume continuation of exports at current Delta salinity levels, not the increased levels that are likely with sea level rise (Figure 4.7).

## **Implications for Export Management Alternatives**

The likely ranges of export water quality and quantity vary with each of the four export management strategies, as do the economic costs and benefits.

### ***Continued Through-Delta Pumping***

With continued reliance on through-Delta pumping to meet export water demands, export water users would face continued supply uncertainties and deteriorating water quality. Exports are likely to become increasingly unreliable, with reduced average quantity and quality because of sea level rise, island failures, and uncertainties in the effects of exports on endangered species. The high costs of treating Delta water for drinking would continue or increase, as would the import of salts into the southern Central Valley, hastening the end of farming in many areas. Eventually, with sea level rise and island flooding, increasing salinities would reduce water exports in all but the wettest years and Delta exports would eventually approximate the no exports alternative.

### ***Peripheral Canal***

Exports taken from the lower Sacramento River would have higher water quality for urban and agricultural purposes and lower water quality costs. If all exports were taken upstream of the Delta, with recent (pre-Wanger-decision) levels of exports, the water quality benefits alone could be

\$300 million to \$1 billion per year by the middle of this century. Whether a peripheral canal would entail economic costs from reductions in export deliveries would depend on the operational and environmental aspects of water management. Upstream intakes would avoid most entrainment issues affecting Delta species. But to avoid entrainment of Chinook salmon and other species living in or passing through the Sacramento River and northern parts of the Delta, the canal might be required at times to divert less water than has occurred in the recent past (Chapter 4), resulting in some costs to water users.

### ***Dual Conveyance***

Initially, a combination of a canal and through-Delta pumping should provide greater water supply reliability than upstream diversion alone. In particular, if dual conveyance could capitalize on its potential physical flexibility to avoid fish entrainment and related problems, it might face fewer regulatory restrictions on exports than either Delta export pumping or a peripheral canal. However, dual conveyance offers more limited water quality benefits than a peripheral canal because of the higher salinity of Delta waters. If all urban water were taken from the canal and all agricultural water continued to be channeled through the Delta, the net water quality benefits as compared with a pure through-Delta strategy would still be roughly \$100 million per year today. Such water quality segregation would require more complex operation of the California Aqueduct (as batch pipelines from refineries do now) and perhaps additional near-Delta storage. Over the longer run, the water supply reliability of a dual facility would diminish as sea level rise and island failures curtail the use of the through-Delta component.

### ***No Exports***

Ending water exports, as a long-term water supply solution, would probably cost at least \$1.5 billion per year or perhaps as much as \$2.5 billion—a substantial sum but not catastrophic for the statewide economy. However, ending or severely reducing exports would be catastrophic for many agricultural areas in the southern Central Valley. This strategy would also reduce the economic basis for funding extensive environmental investments in the Delta.

In sum, from the perspective of the statewide economy, there are clear advantages to moving toward a peripheral canal or dual conveyance system. In addition to reducing the risks of costly disruptions in the water supply from a failure of Delta levees, these options have the potential to reduce the regulatory costs for export users relative to the current through-Delta pumping system. They also provide a substantial windfall in water quality savings for both urban and agricultural water users. However, the benefits and costs of these alternatives might not be equally distributed, depending on the governance and finance policies implemented.



## 7. Policy and Regulatory Challenges

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“If a man neglect to strengthen his dike and do not strengthen it, and a break be made in his dike and the water carry away the farmland, the man in whose dike the break has been made shall restore the grain which he has damaged.”

*The Code of Hammurabi (circa 2250 BCE), translation by Robert Francis Harper (1904)*

### Introduction

To increase the chances of favorable ecosystem and economic outcomes, California needs a policymaking environment that enables decisionmakers to anticipate the changes facing the Delta. This requires effective political leadership, a sound governance and finance system, and an appropriate set of regulatory tools.

Given the large number of stakeholders concerned with Delta outcomes, there is no substitute for higher-level political leadership to help chart a new course for Delta management and negotiate solutions to some of the difficult tradeoffs among human users of Delta resources. Mitigation offers a promising path for resolving some of these tradeoffs while fostering policies that are in the best overall interests of the state. However, given long-term limitations on state and federal funding, it is in both state and local interests for beneficiaries to pay for most Delta actions, rather than delaying urgent decisions with the distracting notion that state and federal governments will provide most funding. The State Water Project and many local water projects provide sound precedents for the principle that water users should pay for the water infrastructure from which they will benefit.<sup>1</sup>

Central issues for Delta governance include setting up better oversight of regional land resources, establishing a reliable funding stream for ecosystem management, and improving the process for balancing human water uses with ecosystem needs. The Delta Vision Blue Ribbon Task Force and the BDCP are each devoting considerable attention to these

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<sup>1</sup> See Lund et al. (2007), Chapter 9, for a discussion of financing and mitigation principles for Delta solutions.

issues, which have also been the subject of legislative proposals (in the context of Senate Bill 27). Although the issues are complex, there are many successful resource management models to draw on elsewhere in California, including regional authorities such as the Coastal Commission and the Tahoe Regional Planning Authority, state land conservancies such as the Coastal Conservancy, and joint powers authorities (Aitchison, 2007). For the thorny question of ensuring stable funding for ecosystem management, California will need to move beyond the recent model of relying on periodic injections of state bond funding. A more appropriate—if more politically difficult—solution is to charge an ecosystem fee for all water diverted from the Delta.<sup>2</sup> Tapping into the windfall savings in water quality would be a natural source of funds if a peripheral canal or dual facility were adopted (Chapter 6).

One key governance issue brings California into new territory: how to provide adequate environmental and political safeguards in the event that a peripheral canal or dual conveyance system is built. There are also questions about whether the current regulatory framework is compatible with the changes coming in the Delta, either as a result of human actions (such as a peripheral canal) or of natural forces (notably, climate change). First, does the current federal and state system for managing Delta water quality allow for anticipatory, versus reactive, interventions? Second—as suggested by the quotation at the beginning of this chapter—what does the prospect of more Delta levee failures and island flooding mean for local and state responsibilities to neighboring landowners? Third, how can upstream diverters become part of a Delta solution? And fourth, how are Delta solutions that aim to balance ecosystem and economic goals likely to fare in the face of an increasingly difficult natural environment for desirable species?

In this chapter, we focus on these four regulatory questions and the governance issue of providing safeguards for a new Delta.<sup>3</sup> Our intent is not to provide the final word on these issues but rather to highlight areas that will need to be addressed squarely as part of any long-term Delta solution.

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<sup>2</sup> See Lund et al. (2007) for a discussion of this issue.

<sup>3</sup> Appendix A provides more details on the regulatory issues discussed here.

## Regulating Water Quality in a Changing Delta

Since the Central Valley Project (CVP) came on line in the 1940s, Delta water quality has been managed to keep salinity low enough for in-Delta agricultural and urban users and project beneficiaries south of the pumps. After the State Water Project (SWP) became operational in the early 1970s, the two projects assumed joint legal responsibility for meeting certain water quality standards for in-Delta users. Over time, water quality standards have been added to protect fish species. The State Water Resources Control Board (SWRCB, “the Board”) has primary authority for adopting water quality standards under federal and state law (respectively, the Clean Water Act (adopted in 1972) and the Porter-Cologne Act (adopted in 1969)).

The Bay-Delta Water Quality Control Plan (WQCP) is the foundational document for Clean Water Act and Porter-Cologne compliance, and it includes measures to protect the legally designated beneficial uses of Delta waters: agriculture, municipal, and industrial uses, and fish and wildlife. The most recent WQCP, finalized in 1995 and updated in 2006, maintains pre-existing standards for agricultural and urban diverters. To protect fish, it also includes a variety of minimum flow requirements, as well as maximum salinity standards at the western edge of the Delta at some times of the year (the so-called “X2” standard). D-1641, adopted in 1999, is the associated water rights decision that designates the SWP and CVP projects as responsible for meeting these water quality standards.

Under this system, all parties are assumed to benefit from lower salinity in the Delta, and the amount of water exported can be reduced and reservoirs operated to maintain standards for fish and in-Delta diverters. For several reasons, this system is likely to run into increasing difficulties. First, the modeling results shown in Chapter 4 confirm concerns raised by some in-Delta interests: At current sea level, a peripheral canal for water exports will make it more difficult to continue to meet salinity standards for some in-Delta diversions (Figure 4.8).

Second, the modeling illustrates that sea level rise or island failures alone will generate similar or worse salinity effects for many users of Delta waters. Failure of some western Delta islands—an increasingly likely

event with sea level rise and other pressures on the levees—will constrain or eliminate through-Delta pumping and many in-Delta diversions. Even if the levees in the western Delta remain intact, one foot of sea level rise, which is quite possible by the middle of this century, could generate frequent violations of salinity standards for agricultural users pumping in the western and central Delta under any export management alternative (Figure 4.8). Reducing exports or upstream diversions may help maintain Delta salinity standards under some scenarios, but this strategy will become increasingly costly.

These changes in the Delta raise two types of conflict relative to current water quality standards. First, a conflict could arise because one set of users (depending on exported water) could maintain or even improve water quality with a different system of water management (a peripheral canal), but another set of users would be left with deteriorating Delta water quality. Second, a conflict could arise over inconsistencies in the water quality standards for different uses. If, as discussed in Chapter 5, it is better for desirable Delta fish species to allow greater variability in Delta salinity conditions across seasons and years, this would require standards that directly conflict with those designed to meet agricultural and urban needs.

The current regulatory system is not prepared to resolve such conflicts. In the extreme, the changes from sea level rise or island failures imply that it would no longer be practical to maintain standards for some currently designated uses of the Delta. Yet, although the Clean Water Act does not guarantee specific levels of water quality to designated uses of Delta waters, it does not allow states to remove designated uses if they are already being served.<sup>4</sup> This restriction is tied to the assumption that direct human actions are the only sources of harm to water sources; the Clean Water Act did not foresee water quality changes because of climate change, such as salinity intrusion. Likewise, the act assumes that standards for different designated uses are not inherently in conflict, as would be the case in a variable Delta. The question facing California is whether flexible solutions to water quality conflicts can be devised, to allow proactive selection of a long-term Delta strategy that will serve the state's residents and the Delta ecosystem better than the deteriorating status quo.

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<sup>4</sup> See Section 40 CFR.131.10 (h).

A peripheral canal, combined with mitigation for loss of Delta farmlands, could protect water quality for agricultural and urban export users as well as in-Delta urban users. It also would be compatible with more variable salinity conditions for fish. Because a canal would not be able to provide all Delta farmers with a substitute source of fresh water, it might be most practical—whether or not it is legally necessary—to develop a complementary program to provide transitional assistance to affected Delta farms.<sup>5</sup> As long as everyone agreed, it might be possible to negotiate the necessary changes in Delta water quality standards. But with holdouts, the problem might be difficult to resolve without legal action.

The state must take the lead in resolving these conflicts, taking a forward-looking view of changing water quality conditions and needs. The SWRCB has the legal authority and the tools to take the lead on this effort, although it lacks the resources, political support, and mandate to do so. The Board recently resolved to develop a multiyear strategic work plan on Delta issues. This is an opportunity to consider future regulatory frameworks that can work best from the long-term standpoint of the ecosystem and the state's economy.<sup>6</sup> An activist SWRCB can push the regulatory discussion with federal, state, and local officials to find realistic ways to live with the changing conditions and uses of Delta waters. Delta salinity is the first of many such issues that California will face as the climate warms. For instance, in-stream temperature standards on many rivers and streams, including many within the Delta watershed, are also regulated under the Clean Water Act and Porter-Cologne, and it may

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<sup>5</sup> Case law going back to the early 20th century has progressively established limits on the extent to which Delta water users are guaranteed water of a certain level of salinity. Salinity standards already vary by water-year type and by location in the Delta in recognition of the excessive costs of meeting higher, uniform standards. It may be possible to modify water quality regulations to allow increasing interannual and seasonal variability by pushing further in this direction—lessening salinity standards in some years (for greater interannual variability) and in later months in the irrigation season (for greater seasonal variability)—without making Delta farming unviable.

<sup>6</sup> Arguably, there is strong set of legal tools and precedents to make the case for giving fish and wildlife, especially endangered species, higher priority in setting water quality standards. These tools include the Public Trust Doctrine, Section 5937 of the Fish and Game Code (fish must be in “good condition” below dams), and the 1986 Racanelli Decision (discussed below).

become increasingly challenging to meet these standards, with longer warm seasons and warmer inflows into reservoirs.

## **Anticipating Increased Risks of Levee Failures**

As highlighted in Chapter 2, the physical forces acting on the Delta suggest an increasing likelihood of levee failures in the coming decades, and for many islands the costs of repair may well exceed the value of economic activity and infrastructure assets that the levees protect. Similarly, the modeling results in Chapter 4 suggest that only the western islands might be important for maintaining Delta salinity standards. These findings suggest that it will not be in the interests of Delta landowners or the state to repair all levees after failures, and that it may also be in the state's interest to develop a strategy for purchasing and preflooding some islands to reduce salinity intrusion from extensive levee failures.

Clearly, additional economic analysis and hydrodynamic modeling work is needed to map out a long-term levee strategy of this type. Important legal issues also need to be considered regarding the potential hydraulic effects of island flooding on landowners on neighboring islands. These effects can include greater wave action and increased underseepage, requiring reinforcement of the neighboring levees to avoid higher flood risk. We estimate that these mitigation costs can be substantial, ranging from several million to more than ten million dollars per island depending on the size of the flooded island and the length of levees affected on neighboring islands.<sup>7</sup>

There is no explicit statutory requirement to mitigate changes to neighboring levees if a levee breaks; in this case, neighboring landowners would need to resort to tort law and would need to prove that the levee owner was negligent or deliberately caused the levee failure. Even if fault were found, it might be difficult to receive payment from the local reclamation districts responsible for nonproject levees, because under the terms of Proposition 218, the districts would not have funds unless island landowners voted to assess themselves. Flooded landowners are unlikely to

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<sup>7</sup> See the spreadsheet accompanying Appendix B. We have included these costs in our analysis of the costs of not repairing Delta islands after levee failures.

have the will or the capacity to do so, particularly for islands that are not to be repaired.

The situation is likely to be quite different if the state is directly involved, and the issues differ for nonproject and project levees. For nonproject levees, the state might purchase islands either as part of a long-term mitigation strategy for Delta landowners or with the intent to pre-flood the islands. In the first case, the state would likely be more exposed financially than private landowners, even if it did not deliberately cause the islands to flood. Preflooding the islands might make the state liable for the consequences to neighboring islands. In short, the state needs to develop a policy regarding neighboring island levees if it gets into the business of buying up Delta lands.

The state does not currently have the option of not repairing project levees after a failure without the agreement of the U.S. Army Corps of Engineers—an action that would likely require congressional approval. Thus, any forward-looking policy regarding project levees—some of which protect highly at-risk islands—needs to anticipate these issues and involve federal consultations well in advance.

## Including Upstream Diverters in a Delta Solution

Most reductions in net Delta outflow are due to upstream diversions and consumptive use of surface water and groundwater (Lund et al., 2007). In an average year, water users upstream of the Delta on the Sacramento and San Joaquin Rivers and their tributaries divert roughly twice the amount of water from the Delta as do export users (Chapter 3). The Delta Vision Task Force argues for the need to involve both types of diversions, not just exports, in meeting ecosystem revitalization goals (Isenberg et al., 2008). Although the SWRCB has broad authority to involve upstream diverters in meeting environmental water quality needs in the Delta, efforts to do so have been very limited to date.

In 1986, the Racanelli Decision (*United States v. State Water Resources Control Board*, 227 Cal Rptr. 161, at 195–1986) clarified that all water rights holders, irrespective of seniority, could be required to participate in meeting water quality standards. The decision made it clear that the Board has the authority to set water quality standards for beneficial uses including, specifically, protection of fish and wildlife. The Environmental Impact

Report for the 1995 WQCP examined several alternatives for placing some responsibility for Delta water quality standards on upstream diverters (State Water Resources Control Board, 1999). The two alternatives that allocated responsibility by order of priority resulted in relatively little participation by upstream diverters, because most have rights senior to the export projects. A third alternative projected a much broader sharing of responsibilities, by relying on proportional cutbacks in upstream diversions on a watershed basis, irrespective of seniority. In the end, the CVP and SWP assumed responsibility for the water quality standards, but deals were made to seek contributions from senior agricultural users on the San Joaquin and Sacramento Rivers, in exchange for financial compensation.

Looking ahead, there is a potential for significant increases in upstream diversions (Whitney, 2008). Potential avenues include perfection of the so-called “state filings”—water rights applications filed by the Department of Finance to reserve priority rights for other users when the CVP and the SWP were built. In addition, upstream water users in the “areas of origin” can receive higher priority for new water rights applications. Presently, over four million acre-feet of water rights applications are pending in the Delta watersheds; most (if not all) would rely on area of origin claims for seniority over the projects.<sup>8</sup> By way of comparison, Delta exports in recent years have averaged roughly six million acre-feet.

The potential for new upstream diversions, even if limited to a portion of the applications on file, raises questions about the long-term reliability of current planning efforts for Delta exports. One alternative to offset greater upstream diversions would be to move from a priority-based approach toward a watershed-based approach, with proportional cutbacks, for regulating water quality. Such an approach might be most consistent with the Public Trust Doctrine. Another would be to increase the use of market-based tools, building on existing arrangements to get senior upstream diverters to release flows in exchange for compensation. As noted in Chapter 6, there is considerable potential for increasing outflows through a combination of higher minimum outflow regulations and market-based mechanisms.

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<sup>8</sup> Data on permit applications are available at <http://www.waterboards.ca.gov/ewrims/>.



## Protecting Endangered Species in the Face of Uncertainty

A central aspect of the current crisis in the Delta is the declining native fish populations, several of which are listed under the federal and state Endangered Species Acts. Judge Wanger’s decision to curtail pumping was a remedial action under federal endangered species law and will result in significantly lower exports than allowed under the WQCP. The current efforts to develop a Bay Delta Conservation Plan reflect water export users’ goals to move to a more flexible regulatory regime for species protection. The BDCP is being designed to serve jointly as a Natural Communities Conservation Plan (NCCP) (under a state law that complements the state Endangered Species Act) and a Habitat Conservation Plan (HCP) under Section 9 of the federal Endangered Species Act. Within a NCCP/HCP framework, the export users would move from being regulated on a species by species basis, with incidental “take” permits for harm done to species, to a regime in which the overall conservation plan for a group of species guides regulatory intervention. With a plan that is sufficiently protective of the stated conservation goals, which must include species recovery under the terms of the NCCP, the export users hope to have assurances that they will not face the type of cutbacks that have occurred under the Wanger ruling.

An NCCP may provide the most promising process for dealing with aquatic species management issues in the Delta; it lays out clear guidelines for conservation goals, supported by scientific review, and it is the only statute that explicitly considers adaptive management as part of the conservation process.<sup>9</sup> Developing such a plan for the Delta will be challenging, given the number of players and the complexity of aquatic habitat and water operations issues. To date, other NCCPs have focused on terrestrial habitat protection, and the “project” at stake is where to allow land development—a relatively straightforward issue, with fewer moving pieces.

Even with an approved plan, BDCP participants will likely continue to face some legal and regulatory uncertainty, judging by the NCCP

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<sup>9</sup> In general, HCP requirements are less stringent, so this plan would likely be driven by the requirements of the NCCP.

experience in Southern California.<sup>10</sup> In the Delta, there is also a persistent risk that some species will not do well, even if the plan's conservation actions are well designed and carried out in earnest. The results of our expert survey show that the scientific community has serious doubts about the viability of delta smelt under any water management alternative, even under the best cases (Figure 5.1). With climate change, the chances of viability decline significantly for this and other key Delta species. In addition to the many existing stressors, water temperature increases will make it harder for some species to find a suitable window of time to spawn and thrive.

The possibility of losing a species because of climate change was not foreseen by either the state or federal Endangered Species Acts. Like the Clean Water Act, these laws were passed in the 1970s, well before climate warming was in the spotlight, and they assume that harm to species in a project area is caused by direct human action. As a result, some important questions have not yet been tested: Can a well-planned NCCP/HCP protect against loss of a species from an external event such as climate change? Would incorporating climate change effects in the plan's adaptive management program—to foster the best conditions for the fish—be adequate to provide coverage?

Even if the Endangered Species Act did not apply if a species declined solely because of climate change, it may be difficult to argue that the CVP and SWP operations are not exacerbating or hastening the risk of extinction. Given the extent of physical manipulation of water in the Delta, proving that the projects play no role will be difficult. Thus, Endangered Species Act enforcement could still shut down or significantly reduce exports, as long as there was a reasonable chance that diversions were contributing to the problem. Issues are likely to arise for other fish, in addition to delta smelt, as evidenced by Judge Wanger's recent ruling concerning winter and spring run Chinook salmon (Chapter 1). The planning process needs to take this risk into account in evaluating the various alternatives and their costs.

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<sup>10</sup> Despite receiving accolades from the country's planning community, San Diego County's NCCP has been held up by lawsuits over whether adequate resources were being devoted to its conservation goals.

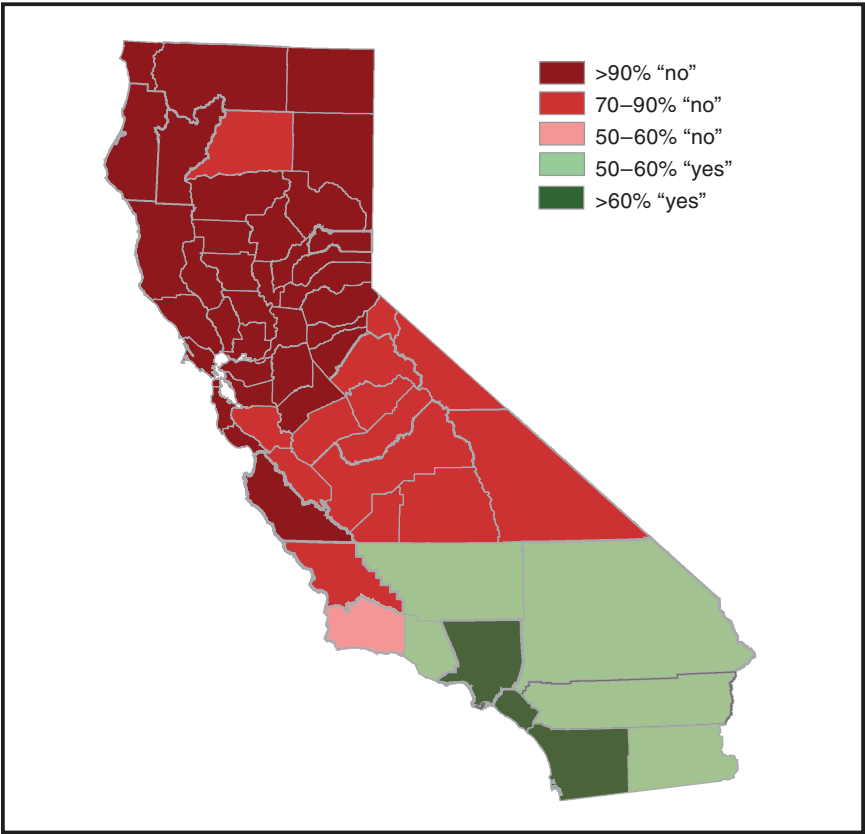
Under current law, the only recourse to a direct conflict between species and economic losses would be a congressional exemption to the Endangered Species Act for the Delta, or a favorable ruling from the “God Squad”—an interagency cabinet-level group that can exempt projects from the act if the economic costs of compliance are too high. These are high-stakes events; to date, exemptions have been granted in only a handful of cases.

## **Governance Safeguards for a Peripheral Canal**

Among the export management alternatives considered in this report, two would involve constructing a peripheral canal. Because this decision would be a major departure from the present system of diversion, it would require new governance mechanisms. The peripheral canal is highly controversial. In June 1982, the last time a peripheral canal was seriously considered, it was rejected by a strong majority of Northern California voters (Figure 7.1). The two main concerns are still being voiced by some today: the potential for a “water grab” by Southern California and the effects of a canal on the Delta ecosystem.

Although the San Francisco Bay Area now depends on the Delta as much as urban Southern California does, Sacramento Valley residents are sensitive to how much water can be exported from their watershed without causing local economic harm. And although there are potential environmental benefits from changing the intake points for water exports, environmentalists want to ensure that enough water is made available for habitat needs in the Delta if export water is diverted upstream.

One way to satisfy these apprehensions would be to provide physical safeguards, such as by building a very small canal. However, this solution would limit the economic benefits from improving the conveyance of water exports, given the variability of rainfall and the scale economies of canal sizing. A very small canal also risks limiting environmental benefits, because it makes it more difficult to allow salinity to vary within the Delta and Suisun Bay and limits flexible adaptive operations that might reduce entrainment of fish at export intakes (Chapter 4). An alternative is to build a canal large enough to benefit from water management opportunities and to provide solid safeguards through the governance system.



**Figure 7.1—County Voting Patterns on Proposition 9 (Peripheral Canal), June 1982**

Providing safeguards to Sacramento Valley residents is largely a political issue, although considerations of “safe yield” to the region’s groundwater basins could also play a role in setting export limits. The problem could be readily dealt with by setting long-term average limits to Delta exports—for instance, at the average of the last 10 or 20 years. This period would need to exceed the common decadal periods of wet and dry years. Such limits could be instituted by regulations, ownership of long-term capacity, or surcharge fees dedicated to environmental restoration or water development in Northern California.

Providing safeguards for the ecosystem requires scientific input. In addition to guaranteed minimum inflows into the Delta for ecosystem needs, the ideal system would provide the ecosystem with variable flows across seasons and years, depending on conditions of the fish and other factors. To allow for this flexibility, a formal Delta Environment Authority might control a sizable amount of conveyance capacity, which could be allocated to Delta inflows, or to lower San Joaquin River flows or leased to export users, depending on ecosystem needs. For some period of time, the minimum inflow requirement could include adequate flows to maintain salinity standards for in-Delta diverters, until this latter goal became unattainable because of sea level rise or island flooding. Export users, too, would have a lower bound of water availability from the canal, which would vary seasonally and by water-year type. Hydrodynamic modeling and analysis by biologists could help establish the size and pattern of these allocations.

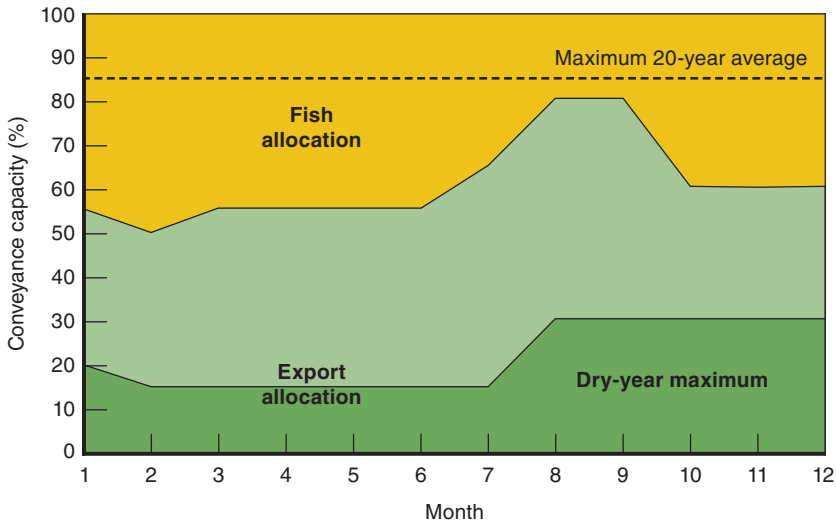
Figure 7.2 provides a simple illustration of such a system. A side benefit of this flexible arrangement is that leasing of the fish allocation on some occasions could create a stream of income for ecosystem investments.

Some parties could still worry that the system could be undone through the political process—for instance, by a change in the laws governing the canal or the public institutions that manage it. To provide legal safeguards, two alternative approaches have recently been proposed. The first, suggested in SB 27, is to provide a constitutional protection of export limits.<sup>11</sup> An alternative proposal is to consider a type of public/private partnership for managing the canal, with a private party (for instance, an environmental water trust) to manage the flexible allocation for the ecosystem.<sup>12</sup> With a private partner, the governance rules for canal operation would be subject to private contracts law. If the agreement specified appropriate compensation for abrogation of the contract terms, this could make the system less vulnerable to modification by administrative or legislative fiat.

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<sup>11</sup> Constitutional protections of north coast rivers and Delta water quality were part of the agreement for the peripheral canal proposal in the early 1980s. Dissatisfaction with these environmental protections on the part of some southern Central Valley agricultural interests was a factor in the canal's defeat (Hundley, 2001).

<sup>12</sup> See Natural Heritage Institute (2008) for a discussion of this issue.



NOTES: Additional Delta outflow requirements also would exist (not shown here). Annual and monthly percentages shown here are for illustration only. In dry years, export users could convey only the volume represented in the dark green area. In wet years, export allocations would extend to the top of the light green area. The fish allocation (yellow area) would be available for various Delta environmental uses or for lease to export users, when the water was not needed for fish. Over a 20-year period, exports would not be allowed to exceed a maximum 20-year average (or other appropriate threshold), to protect interests in the Sacramento Valley watershed

Figure 7.2—Allocation of Peripheral Canal Capacity in a System with Safeguards

## Governance and Decisionmaking for a New Delta

As we argued in *Envisioning Futures*, the CALFED experience of the 1990s and early 2000s shows that stakeholder processes cannot be relied on to make major strategic decisions for the Delta, because some interests can block decisions by arguing to maintain the status quo. Today, prospects for stakeholder decisionmaking are further dimmed by diminishing state and federal funding to provide external incentives for agreement. The urgency and magnitude of the Delta’s problems require more capable frameworks for making strategic decisions. The transition to a new Delta will require a fundamental reorganization of the Delta’s governance and regulatory framework. This task is best undertaken by the legislature and governor, in consultation with local governments, stakeholders, and the federal

government. The state attorney general's office might begin this process with a white paper on available legal and institutional options.

California has made major strategic decisions regarding water in the past, such as flood control early in the 20th century and the development of major projects in the middle of the last century (Kelley, 1989; Lund et al., 2007, Chapter 2). In both cases, decisions were preceded by long periods of controversy. But persistent crises and realization of the importance of strategic change ultimately prevailed in effecting change. These decisions reconfigured existing local governments and state and federal agencies to implement fundamentally new directions in water management. Without comparable decisions today, Delta management will remain in the realm of tinkering with the deteriorating status quo until court decisions or physical catastrophe intervene.

Affirming a strategic decision alone is insufficient. Real institutional, financial, and technical capability and authority must also be created to implement the decision. Establishing such capability, in a state with many other problems and few available funds, will require financial and leadership involvement from the beneficiaries of implementation.

## Conclusion

In sum, although opportunities exist to improve the economic and environmental outcomes in the Delta, innovative solutions could face significant legal and regulatory hurdles. The first issue is the inflexibility of the Clean Water Act. Sea level rise, climate change, the needs of the Delta ecosystem, and water quality and reliability concerns for water export users are all pushing in the direction of more variable Delta salinity, which could preclude some present agricultural uses. The SWRCB will need to work with federal officials to see how California can make the necessary regulatory changes to Delta water quality standards, while remaining in compliance with federal law.

To build a peripheral canal, which could provide numerous water quality and reliability benefits, it will be necessary to overcome concerns about the unreliability of current legal protections for the environment and upstream users. Many of the safeguards these parties seek could be provided through a governance structure that ensures a flexible allocation of water for the ecosystem and limits long-term export volumes from upstream

basins. This would allow the sizing of the canal to be decided on the basis of optimal water management opportunities for both human uses and the Delta ecosystem, rather than on fears that too much water might be diverted.

Current planning processes will need to consider the continued risk of water export cuts, even if a canal is built. To seek greater regulatory certainty, export users are currently pursuing a more comprehensive approach to habitat protection and species recovery in the Delta within an NCCP/HCP framework. However, the risks to species are high, and there are unanswered questions regarding the extent to which such a plan would protect the projects if species continue to decline, as long as exports can be linked to the problem. These risks will increase with climate change and the associated rise in water temperatures. In addition, the projects face cuts from increased diversions in upstream watersheds, which would be senior in priority under the area of origin laws. Regulatory and market approaches will have to be pursued to lessen this risk.

The state also will need to engage in active planning to anticipate the changes in Delta landscapes with the increased risk of island flooding. Some islands may not be worth repairing because of their economic values, and a policy of preflooding some islands may be warranted to limit the risks of catastrophic failure. If the state develops a policy to acquire Delta lands—either to ease transitions for Delta farmers or to facilitate preflooding—it must also consider the potential costs to neighboring island levees that could be affected by island flooding. Forward-looking consultations with federal agencies are also required to develop new policies regarding the project levees that form part of federally authorized flood control projects.

The transition to a new Delta will require a fundamental reorganization of the Delta's governance and regulation framework. This task is best undertaken by the legislature and governor, in consultation with local governments, stakeholders, and the federal government. The state attorney general's office might begin this process with a white paper on available legal and institutional options.



# 8. Decision Analysis for Delta Exports

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“Errors using inadequate data are much less than those using no data at all.”

*Charles Babbage (1792–1871)*

## Introduction

The Delta poses a variety of highly complex problems with a myriad of uncertainties. These troublesome characteristics are common to many other problems, ranging from public policy issues such as national defense and school system planning to personal career and retirement planning. To address all aspects of such problems simultaneously is beyond human abilities and comprehension. To solve complex problems, it is first necessary to organize them into smaller components that can be understood and solved sequentially, to provide insights into how to solve other pieces and to indicate promising overall strategies.

In this chapter, we organize recent scientific and technical findings and assessments summarized earlier in this report to evaluate each export management strategy with respect to the two co-equal objectives of environmental and water supply performance, measured in terms of native fish population viability and statewide economic costs of water supply. In evaluating these strategic decisions, it is important to recognize that not everything is known (or can be known) and that uncertain future events will require responses. The analysis presented here aims to incorporate uncertainties explicitly, by considering ranges of values for costs and other outcomes. In this way, the analysis provides a basis for weighing alternatives despite uncertainties. Society can rarely afford to make decisions without uncertainty. In the Delta, postponing a strategic decision because of uncertainty amounts to making a decision to continue the deteriorating status quo.

# Decision Analysis Applied to the Delta Export Alternatives

To make this economic and ecosystem assessment, we employ formal decision analysis, incorporating the costs and opportunities of things going wrong and things going well for each export strategy. A detailed discussion of the approach, method, and assumptions of this formal analysis appears in Appendix J, along with the spreadsheet used for the calculations.

From a statewide economic point of view, the export management strategies for the Delta can be depicted as in Figure 8.1.

The box at the left-hand side represents the initial decision to use a peripheral canal intake, employ “dual” export facilities, end water exports, or continue through-Delta pumping. The simplest choice to represent is ending Delta exports, which results in a direct and relatively certain cost (as

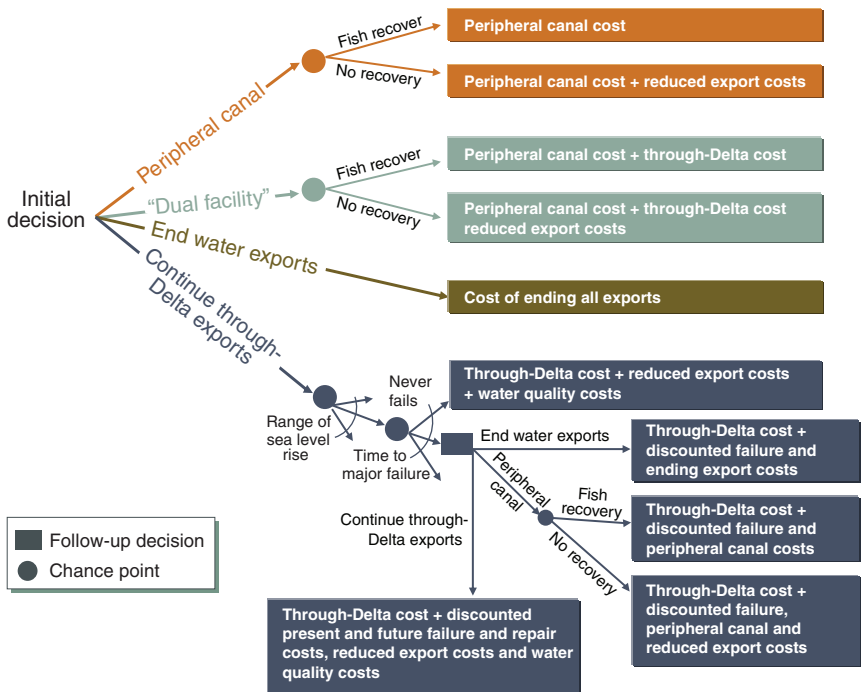


Figure 8.1—Decision Tree for Strategic Long-Term Delta Export Decision from Statewide Economic Perspective

discussed below), summarized or valued in a box on the right-hand side of this option.

The decision to build a peripheral canal is more complex, because it is uncertain how a canal will affect the major fish species of concern for the Delta. In its simplest form, this uncertainty can be represented as two possible outcomes: Either the fish recover or they do not recover (as judged by biological, political, or legal standards). This uncertainty cannot be resolved until the canal has been built; it is represented in the decision tree by a circle with two chance events: fish recovery or failure of the fish to recover. In the happy event of fish recovery, operation of the peripheral canal is relatively unfettered. In this case, the cost of the canal with fish recovery is represented in the box on the right-hand side as the cost of the peripheral canal. However, if fish populations do not recover, exports from a peripheral canal would likely be subject to legal and political pressure for substantial cutbacks, which would incur substantial economic costs. As discussed in Chapters 5 and 7, there are biological and legal reasons to expect legal and political pressure to reduce exports from a peripheral canal. The costs of reduced peripheral canal exports are included in the boxed costs for this combination of choice and chance event. The expected cost for a peripheral canal would then be the average of the costs for these two chance events, with each event cost weighted by our assessment of the probability of each outcome.

A dual conveyance alternative combines a peripheral canal with continued through-Delta pumping. This alternative, as we represent it, combines the costs and probabilities of a peripheral canal with additional costs for continued use of through-Delta pumping. Other more complex representations of dual conveyance alternatives could be employed, but at this stage, the range of dual conveyance proposals is still poorly defined, making a simple representation most appropriate. For example, the current representation of dual conveyance cost does not include water quality costs or damages from extensive levee failures.

The most complex choice is to continue exclusively with through-Delta pumping. Here, the major chance event is an extensive failure of Delta islands, which is a function of the rate of sea level rise and other physical drivers of change discussed in Chapter 2. For each uncertain rate of sea level rise, there is a different probability of extensive Delta island failures.

This is represented by a second circle, representing different years before an extensive levee failure. If the Delta never experiences extensive levee failure, then the cost is the sum of costs for through-Delta facilities, the costs of any reduced exports from continued through-Delta pumping, and additional water quality costs for urban and agricultural areas receiving Delta water, which is more saline than water that would be drawn into a canal further upstream on the Sacramento River (Chapter 6).

When there is an extensive failure of Delta levees, there is another follow-up decision (known as a “recourse” choice) to be made—to repair and continue through-Delta pumping, to end Delta exports, or to construct a peripheral canal. These choices have a structure similar to those discussed above. The total cost for each recourse choice includes not only the costs of the recourse choice but also the by-then “sunk” costs of through-Delta facilities and the damage costs of extensive Delta island failure.

## Information Needed for Decision Analysis

Following this structure of the decision problem, from a statewide economic perspective, a series of 16 questions must be answered to complete the analysis. The 16 questions appear in Table 8.1, along with our suggested range of answers. These questions take into account future sea level rise (#1), the likelihood of extensive Delta levee failure and how it varies with sea level rise (#2, 3), the likelihood of being able to maintain viable fish populations with different intake strategies (#4–#7), the reductions in exports likely for each strategy if the fish are not recovering (#8, #9), and the economic costs of implementing each strategy and the costs of failures or reduced or ended water exports (#10–#16).

To better represent the uncertainties and many other complexities of the problem, we offer both high and low values for each parameter. Fish population viability estimates are undertaken for two key Delta species. For delta smelt, viability is defined as achieving sufficient recovery to avoid Endangered Species Act restrictions on water exports. For fall-run Chinook salmon, it is defined as maintaining adequate populations to support commercial and recreational fisheries. A detailed discussion of our reasoning for selecting the values for each answer appears in Appendix J.

The use of ranges of costs and probabilities implicitly captures additional uncertainties that are not explicitly included here. We believe

Table 8.1

Decision Analysis Questions and Answers Recommended by the Authors

Question	Low Value	High Value
<b>Sea level rise (ft)</b>		
1. How much will sea level rise by 2050?	0.5	1.5
<b>Likelihood of extensive Delta failure by 2050 (annual failure probability in parentheses) (%)</b>		
2. With the minimum sea level rise?	34 (1)	88 (5)
3. With the maximum sea level rise?	57 (2)	95 (7)
<b>Population viability in 2050 for delta smelt (Chinook salmon in parentheses) (%)</b>		
4. What is the likelihood of viable fish populations with continued through-Delta pumping?	5 (10)	30 (30)
5. What is the likelihood of viable fish populations with no Delta exports?	30 (40)	60 (80)
6. What is the likelihood of viable fish populations with a peripheral canal?	10 (20)	40 (50)
7. What is the likelihood of viable fish populations with dual conveyance?	10 (20)	40 (50)
8. By what proportion would exports be reduced for fish protection with continued through-Delta pumping?	25	40
9. If the fish continue to decline, by what proportion would peripheral canal water exports be reduced?	25	40
<b>Economic and financial costs (\$ billion)</b>		
10. What is the construction cost of a peripheral canal?	4.75	9.75
11. What is the additional drinking and agricultural water quality cost of Delta water?	0.3/year	1.0/year
12. What is the annualized cost of ending Delta exports?	1.5/year	2.5/year
13. What is the annualized cost to maintain through-Delta pumping?	0.15/year	0.4/year
14. What is the cost to water users of a sudden extensive failure of Delta levees?	7.8	15.7
15. What is the average cost to repair an extensive Delta levee failure for water supply?	0.2	2.5
16. What exponent relates export reduction to economic cost?	2	3

SOURCE: Appendix J.

that this formulation of the problem, although relatively simple, is sufficiently rigorous and understandable to provide insights into desirable choices for the Delta intake decision. (Occasionally, a more rigorous formulation becomes less understandable and obscures any resulting insights, sometimes called “rigor mortis.”)

## Comparing the Water Export Alternatives

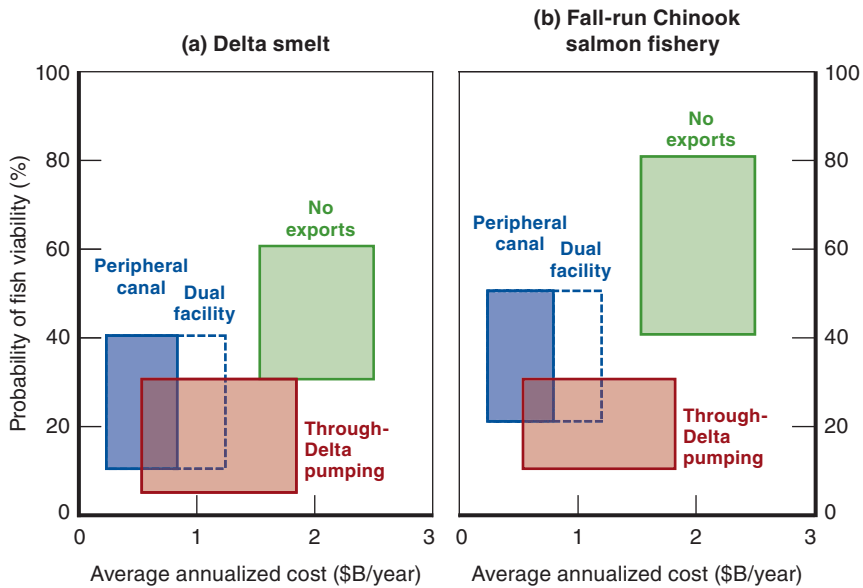
Spreadsheet calculations were used to determine the statewide economic costs and probabilities of fish population viabilities for each of the four alternatives using the decision analysis framework presented in Figure 8.1 and the ranges of estimates provided in Table 8.1. Table 8.2 summarizes the results of these calculations. Figure 8.2 presents these same results graphically.

For some alternatives, the range of likely economic performance is quite broad, reflecting uncertainties about cost. In particular, for continued through-Delta pumping, the expected costs range from as low as \$550 million to nearly \$1.9 billion per year. A key uncertainty for this option is how soon the system will be damaged by a large-scale levee failure. For fish, the ranges reflect the considerable uncertainties about species performance, depending in part on how carefully the ecosystem components are managed, as well as on influences from external sources (i.e., for salmon, the ocean and upper watershed).

**Table 8.2**  
**Annual Costs and Likelihood of Fish Population Viability Under Delta Export Alternatives, 2050**

Alternative	Average Cost (\$ billion/year)	Likelihood of Viable Populations (%)	
		Delta Smelt Population	Fall-Run Chinook Salmon Fishery
Continuing through-Delta exports	0.55–1.86	5–30	10–30
Peripheral canal	0.25–0.85	10–40	20–50
Dual conveyance	0.25–1.25	10–40	20–50
No exports	1.50–2.50	30–60	40–80

SOURCE: Appendix J.



SOURCE: Appendix J.

**Figure 8.2—Range of Costs and Fish Population Viability for Delta Export Alternatives in 2050**

Despite these uncertainties, some clear comparisons emerge. In terms of statewide economic cost, the most likely ordering of alternatives is peripheral canal (best), followed by dual conveyance, continued through-Delta pumping, and, in last place, no exports. Even with relatively high construction costs (on the order of \$10 billion) and 40 percent pumping cutbacks to support endangered fish species, the costs of a peripheral canal do not exceed \$1 billion per year.

Dual conveyance is potentially more costly, because it might entail additional infrastructure costs to maintain the viability of through-Delta pumping. Costs also could be somewhat higher in this alternative because of the increased water quality costs for urban and agricultural users of the portion of water pumped through the Delta and the costs of repairing extensive Delta levee failures.

Several key drivers lead to higher costs for continued through-Delta pumping. First, by mid-century, the water quality costs of taking water from the Delta are on the order of \$300 million to \$1 billion per year, every

year. Second, this alternative requires significant investments, initially to fortify the key levees and perhaps also to improve Delta channels and ultimately to build a peripheral canal when the levee system fails.<sup>1</sup> Third, a catastrophic failure of key levees would cause large one-time costs of \$8 billion to \$16 billion.

The no exports alternative, in contrast, involves considerable costs outside the Delta itself, as water users develop alternative, higher-cost sources and reduce agricultural and urban use, particularly for agriculture in the southern Central Valley.

The most likely ordering is quite different for fish viability, with the no exports alternative the best, followed by peripheral canal and dual conveyance systems (tied), and continued through-Delta pumping in last place. There is a broad consensus among estuarine experts that ending exports is likely to be best for a range of desirable fish species. Benefits include ending the harmful entrainment and unnatural flow patterns generated by the southern Delta pumps, as well as providing more water for aquatic habitat. A peripheral canal also provides the first of these benefits if it is designed and operated to minimize new entrainment problems at the upstream intake.

Although in principle a dual facility offers some additional flexibility for water management, we do not believe that this alternative will have appreciably different outcomes for either delta smelt or salmon from a pure canal alternative. Finally, continued through-Delta pumping is the least beneficial for fish, given the problems of entrainment and disruption created by the southern Delta pumps. Through-Delta pumping also prevents the more flexible management of environmental water flows to increase aquatic habitat variability. Eventually, through-Delta pumping, even at reduced levels, will lead either to the elimination of exports entirely or to the construction of a peripheral canal (the least expensive recourse after extensive failure).

How do the alternatives compare when environmental and economic performance are considered together, as co-equal objectives?

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<sup>1</sup> Our analysis finds that a peripheral canal would be built after massive levee failure because this would be the least expensive response. If, instead, the decision was made to rebuild the failed levees or to end exports, the expected cost of the through-Delta strategy would be higher than the range presented here.



- The peripheral canal and dual conveyance alternatives are very likely to perform better than continued through-Delta pumping on both objectives. We calculate that the peripheral canal has a two-thirds chance of outperforming through-Delta pumping on both economic and fish objectives; for dual conveyance, the chance is 60 percent (see Appendix J for details). In contrast, through-Delta pumping has only a 5 percent chance of outperforming the two canal-based alternatives on both co-equal objectives.
- We find little technical reason to prefer dual conveyance over a peripheral canal. The two alternatives are likely to perform equally from a fish perspective, and dual conveyance is likely to be more costly. Nevertheless, for an interim period, it may be valuable to maintain through-Delta pumping as part of a dual system, to maintain water quality for Delta farmers and provide additional flexibility for exports and environmental operations.
- A clear tradeoff exists between a peripheral canal and dual conveyance and the alternative of ending exports. Peripheral canal and dual conveyance costs are lower, whereas ending exports is better for fish. Selecting between these alternatives will require a value judgment.

Are the policy options limited to a choice between (1) a peripheral canal/dual conveyance approach with moderate probabilities of viable fish populations and lower economic costs and (2) ending exports with very high costs and somewhat higher probabilities of maintaining fish populations? No. Hybrid approaches exist where some savings from a peripheral canal/dual conveyance approach are invested in fish habitat and restoration activities to raise the likelihood of improving fish prospects. Alternatively, reducing the volume of exports from a peripheral canal or dual conveyance also might improve the fish population prospects of these alternatives. The former approach may provide the most useful compromise, because it provides a key to proactive investments in habitat improvement, which are likely to be needed under any export management alternative (Chapter 5).

How stable and robust are these conclusions? We have tested them by varying the range of answers and making some changes in the calculation methods. In general, these conclusions seem to be robust to

the uncertainties and complexities not included explicitly here. But others are welcome to provide their own estimates (hopefully with technical justifications) to test these conclusions. The spreadsheet provided with Appendix J is designed to allow users to modify the answers to the 16 questions and see how the results change.

## Implementation Issues

We find that there is a substantial scientific and technical basis for making a policy decision on the strategy for water exports from the Delta. However, a host of major implementation issues remain for guiding the creation of a new Delta, including Delta island policies; governance, regulatory, and finance institutions; operations; and ecosystem management.

Although the physical forces driving the Delta and the economic analysis presented in Chapter 2 and Appendix B indicate that it will be uneconomical and ultimately impossible to maintain all Delta levees, Californians have only begun to discuss which islands should be repaired, how failed islands should be managed (i.e., converting some islands to aquatic or terrestrial habitat), and other potential policies for Delta islands. As noted in Chapter 7, these decisions also raise important legal and regulatory questions regarding levee policy. A systematic and comparative examination of Delta island and land use policy is needed from a realistic long-term perspective, with accompanying policy discussions and decisions.

As discussed in Chapter 7, governing and financing arrangements and the regulatory regime for water quality, instream flows, and endangered species management also will need to transition to be suitable for the new Delta. These new arrangements must be authoritatively defined by the state and must fit with federal requirements.

Our current report largely avoids detailed discussions of water operations, because of the short time frame of the study and insufficient capability to perform detailed analysis. Systematic study of operational issues will be needed over an indefinite period, even many years after any new Delta policies have been implemented, given changing problems and understanding of the Delta. This will require substantially new and different types of hydrodynamic, operations, and planning analysis. Many

months of analysis will be needed to inform discussions of preliminary operating policies for policy and planning purposes and negotiations.

The design and implementation of ecosystem management activities is perhaps the most important and difficult area where additional implementation work is required. For decades, California has neglected the synthetic scientific thinking and difficult policy discussions required to develop a sustainable vision of the kind of ecosystem that can and should be maintained in the Delta. A quantitative analysis capability, which assesses how water operations mesh with ecological objectives, perhaps similar to the Sacramento River Ecological Flow Tools decision support system, might better inform discussions of tradeoffs among water export and environmental management objectives.

Beyond these general areas, specific, detailed implementation issues must be resolved over the course of policy, planning, design, construction, and operations for the new Delta. Table 8.3 highlights the types of decisions required for a peripheral canal alternative (as detailed in Appendix G); similar lists could be developed for the other three alternatives examined in this report. These issues all require an ability to make and implement policy decisions. Most of these decisions would be aided considerably with additional scientific and technical information, which still needs to be developed or assembled from previous studies. The Delta's transition will bring Californians into unfamiliar territory, where intuition and an understanding based on how things have operated in the past will become less-reliable predictors. Only scientific and technical analysis can help guide the way through this new landscape.

## **The Timing of Delta Decisions and Consequences**

Another aspect of Delta decisionmaking that we have not considered in detail is timing—for instance, how one might phase in a new export management regime. To provide some insight on this issue, Figure 8.3 presents a conceptual view of how export alternatives may perform over time and the choices California will face. Water exports are currently declining from historical high levels as a result of court rulings regarding endangered species. Additional species listings are likely to cause further export reductions in the near term. The accumulating effects of land subsidence, sea level rise, worsening floods, and earthquakes will make

**Table 8.3**  
**Design and Operations Options for a Peripheral Canal**

<b>Infrastructure design</b>	<b>Operation policies</b>
Upstream intake locations	Operating strategy
Additional intake locations	Constrained delivery policies
Outlet locations	Monitoring
Total flow capacity	
Fish screening	<b>Delta land and water management</b>
Sedimentation basin	Aquatic and terrestrial habitat
Booster pumping	Flood management
Right-of-way	Levees
Channel elevations and lining	Agriculture
Stream channel crossing	Recreation
Associated operational water storage	
Associated recreational facilities	<b>Governance, regulation, and finance</b>
	Ownership
<b>Major adjustments and mitigations</b>	Governance authority
Delta farmers	Regulatory oversight
Contra Costa Water District	Finance and repayment
North Bay Aqueduct	Terrestrial and aquatic habitat management
Delta towns	
Recreation	
Environment	

SOURCE: Appendix G.

continuation of through-Delta pumping less reliable and more costly over time but will leave peripheral canal exports relatively unaffected. However, it will take some time before a peripheral canal can be constructed. How well a dual conveyance alternative ultimately performs will depend on the size of the canal component. If the canal is sufficiently large, it can take an increasing share of exports as through-Delta pumping becomes less viable. As Figure 8.3 highlights, the ability of each alternative to support fish populations also significantly affects its ability to support exports.

## Conclusions

We developed a formal decision analysis tool, in the form of a spreadsheet, to examine long-term strategies concerning water exports from the Delta. The options examined include (a) pumping water through the Delta (the current policy), (b) taking water exports around the Delta

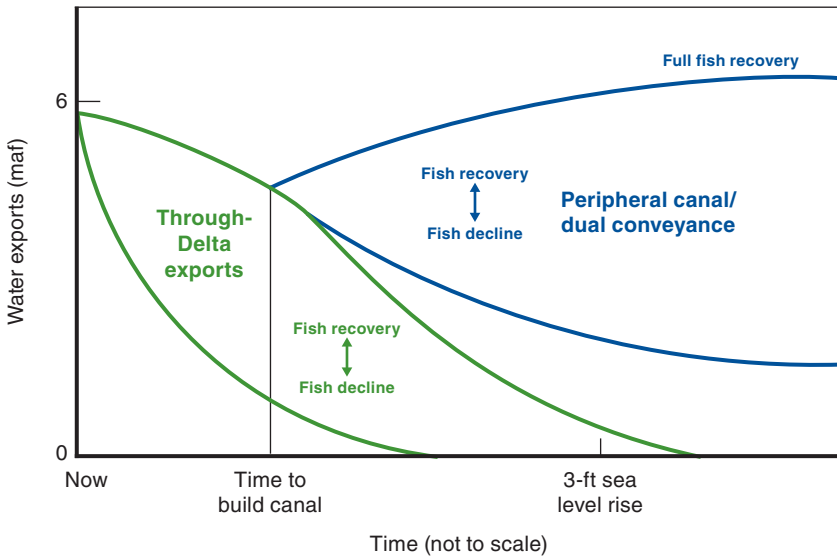


Figure 8.3—Delta Export Transitions over Time

through a peripheral canal, (c) combining through-Delta pumping and a peripheral canal (dual conveyance), or (d) ending Delta water exports altogether. The analysis considers two main criteria for performance, consistent with the Delta Vision Blue Ribbon Task Force’s identification of two co-equal objectives for the Delta: ecosystem revitalization and water supply. We measure ecosystem revitalization by the yardstick of viability of two desirable Delta fish populations and water supply by the yardstick of economic costs of water supply and quality. We focus on outcomes for the middle of this century. This is a sufficiently long horizon to incorporate the effects of natural forces acting on the Delta, such as sea level rise, and yet close enough in time to be relevant to today’s decisions about major infrastructure investments.

Our results suggest that continued use of through-Delta pumping is risky from both economic and environmental perspectives and is unlikely to be the best strategy from a statewide economic perspective or from the perspective of improving the viability of desired fish species. After an extensive set of levee failures in the Delta, it will be less costly to replace through-Delta pumping with a peripheral canal than to rebuild the

through-Delta system. Building a canal sooner, before an extensive levee failure, is less costly to the economy. A proactive policy may avoid the high costs of an abrupt interruption of water supplies and might provide significant water quality savings and public health benefits. A peripheral canal also is likely to be better for a variety of desirable fish species. A dual conveyance alternative has similar prospects for Delta fish, at potentially higher costs.

Ending Delta exports entirely is the most favorable strategy for maintaining the viability of desirable fish populations. However, it comes with the greatest statewide economic costs and would deprive environmental management in the Delta of a potential revenue source.

The hundreds of millions of dollars of lower average annual costs from the peripheral canal and dual conveyance strategies provide a statewide resource for environmental investments in the Delta. Redirecting some of this economic gain to habitat acquisition and other improvements for fish species might improve the viability of fish in these alternatives. Reducing exports at times might have a similar function, at a higher economic cost. To succeed in meeting economic and environmental goals, California will need a more coherent program of operational management for the new export facilities, strongly coordinated with habitat management, than has been present in export management programs to date.

# 9. Conclusions and Recommendations

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“The secret of getting ahead is getting started. The secret of getting started is breaking your complex, overwhelming tasks into small manageable tasks, and then starting on the first one.”

*Mark Twain (1835–1910)*

## Conclusions

In this report, we have focused on how California’s options for making sound long-term management decisions for the Delta will be affected by climate change and other factors. Here, we summarize our conclusions regarding the Delta’s changing landscape, the potential for and challenges of improving the Delta’s ecosystem, the alternatives for managing water exports from the Delta, and the regulatory challenges for the Delta of the future.

### *The Changing Delta Landscape*

Fundamental changes are inevitable for the Delta. “Restoring the Delta” is an unrealistic and perhaps meaningless notion given the historical changes that have occurred in the Delta and the immutable forces that will operate on it for decades to come.

1. **Sea level rise, earthquakes, continued land subsidence, and higher winter flood flows will increase the frequency of Delta island failures and the costs of preventing and recovering from failures.** Under today’s risk conditions, more than half of the Delta’s islands have a 90 percent chance of failing some time in the next 50 years. These drivers of change, including sea level rise of approximately one foot by 2050 and three feet by 2100 and escalating threat of earthquakes, significantly increase this likelihood of failure over time. These risk factors are considerably higher than those reported in *Envisioning Futures*.

2. **Maintaining all Delta islands is not cost-effective.** Reducing the frequency of island flooding in the Delta would cost many billions of dollars. From a water supply perspective, only the western Delta islands might be essential for keeping salinity away from export pumps in the southern Delta (before significant sea level rise brings salinity farther into the Delta in any event). Continued investment in some islands can be supported by the economic value of on-island activities and infrastructure such as roads and rail lines. But for 10 to 20 significant Delta islands, there is no compelling economic basis for state investments in levee upgrades or in repairing and restoring the islands after failure.
3. **The Delta of the future will be different.** Given the magnitude of projected change during this century, it is unreasonable to assume that the current levee network will be maintained indefinitely at increasing costs and diminishing benefit. These costs, coupled with increasing risk factors, ensure that the Delta landscape of the future will be significantly different from the Delta of the past. Within the next 50 years, the Delta very likely will contain large areas of open water left after islands have flooded.
4. **California is unprepared for the changes that will occur in the Delta.** The institutions, regulations, infrastructure, and expectations for the Delta are built around maintaining the Delta in an unsustainable and deteriorating condition. It is time to prepare for a very different Delta, with a different ecosystem and different water supply and land use capabilities. With timely, purposeful action, there is some choice in what the Delta will become.

### *Fish and the Delta Ecosystem*

Promising opportunities lie ahead for improving conditions for desirable fish and wildlife in the Delta. For fish, there is bound to be improvement in aquatic habitat as more is created by island flooding. Changes in water operations and habitat management can improve conditions not only for fish but also for other wildlife, especially waterfowl.



5. **Large-scale flooding of Delta islands is likely to create more favorable conditions for fish.** In recent years the Delta ecosystem has shifted to a less-suitable state for desirable fish species. Future island flooding will significantly alter the Delta landscape, creating habitat that is likely to be no worse and potentially better habitat for most desirable fish. Besides expanding the extent and volume of aquatic habitat in the Delta, large-scale flooding will greatly alter water movement through the Delta. The suitability of the new open-water habitats for desirable species will depend in part on the responses of harmful invasive species, including overbite clam and Brazilian waterweed, to the changed system. A proactive experimental approach is required to guide the evolution of habitat in these flooded areas, which will be larger and deeper than the currently flooded islands (e.g., Franks Tract), and are poor models for the future landscape.
6. **More diverse habitat is fundamental to improving conditions for desirable fish, and greater variability in Delta water flow and quality is part of this strategy.** In *Envisioning Futures*, we argued that changes in Delta water management that allow for greater spatial and temporal variability in water flows and quality (salinity, turbidity, etc.) could improve conditions for native fishes while making conditions less favorable for invasive species. Analysis done in the past year by ourselves and others reinforces this view. In addition to increasing the variability in water conditions, actions to benefit desirable species should include increasing the extent of floodplain and tidal marsh habitat within the Delta. Major opportunities to create such diverse habitat conditions exist in the northern Delta (Cache Slough region), Suisun Marsh, and other areas.
7. **Water export alternatives matter for fish.** The current system of through-Delta pumping is the least desirable alternative from an environmental perspective. In addition to killing some fish at the pumps, the present system alters flow patterns within the Delta, moving desirable species to undesirable habitats. A peripheral canal could reduce these problems, while allowing Delta waters to be managed for greater variability. Dual conveyance—combining a peripheral canal with continued through-Delta pumping—may offer opportunities to avoid killing fish under some circumstances.

But overall, dual conveyance is not likely to be better for fish than a peripheral canal operated on its own. Eliminating exports entirely is the most promising alternative for key species, including delta smelt, longfin smelt, and the four runs of Chinook salmon. However, careful management of water exports with a peripheral canal or dual conveyance—with substantial complementary ecosystem investments—can significantly improve the compatibility of continued exports with rebuilding viable populations of desirable species

8. **Rebuilding large, self-sustaining populations of desirable Delta fish species will require large and carefully designed ecosystem investments.** No matter which water export option is adopted in the future, large investments are needed for habitat acquisition, restoration, and improvement, and for increasing scientific knowledge to effectively manage desirable species (native fishes and others that do well under similar conditions). Delaying these investments will increase their costs, reduce the likelihood of fish population recovery, and increase the chance of water export reductions.
9. **Some species in the Delta are likely to be sustained only with heroic efforts.** The prospects for some Delta species are not good, even if society does everything possible to help them, as fast as possible. For example, delta smelt's very survival is threatened by rising water temperatures (from climate change) on top of all the other factors. The Delta is also likely to continue to be a poor environment for juvenile Chinook salmon under most likely scenarios, increasing the difficulty of saving the listed spring and winter runs of Chinook salmon and of sustaining commercial salmon fisheries. The potential for losing some species over the next 50 years poses great environmental, legal, and regulatory challenges.

### *Long-Term Water Export Alternatives*

For water exports, time favors a peripheral canal and is unfavorable to other alternatives. A peripheral canal is an unavoidable component of a long-term solution that serves both economic and ecosystem objectives. Table 9.1 presents a summary comparison of the four alternatives for water exports in the context of such a transition, with policy decisions and investments hopefully proceeding in advance of catastrophes.

**Table 9.1**  
**Summary Comparison of Water Export Alternatives**

Alternative	Performance
Continued through-Delta exports	Increasingly unstable and costly solution
Dual conveyance	Interim solution for transition to peripheral canal
Peripheral canal	Potential to provide both cost-effective water supply and improved fish viability
No exports	Best for fish but most costly to the economy; ultimate outcome without a peripheral canal

10. **Sea level rise will make through-Delta pumping increasingly unattractive and eventually infeasible.** Even if the existing levee network could be maintained through unprecedented investments, worsening Delta water quality resulting from sea level rise will steadily reduce the economic value of water exports from within the Delta. The current costs of Delta salinity are already significant for southern Central Valley agriculture and urban drinking water treatment. More saline Delta exports will reduce the viability of agriculture in this region and increase costs of and health risks from drinking water from the Delta. Alternatively, higher salinity will impose a direct water supply cost by requiring higher outflows to repel seawater from the pumps. With three feet of sea level rise—quite possible by late in this century—through-Delta pumping may no longer provide a major source of fresh water without large increases in Delta outflows, even if the western islands can be kept intact. Even reduced export alternatives such as the “opportunistic pumping” strategy identified in *Envisioning Futures*, which involves taking water from the Delta only when flows are freshest, will become less frequent, less reliable, and of poorer quality. Opportunistic pumping also will be limited by environmental constraints, because the freshest flows (generally in winter and spring) tend to occur at times when pumping cutbacks may be necessary to protect desirable fish.

11. **The long-term water export choice is between building a peripheral canal and ending Delta exports.** Given its unreliability, increasing costs, and environmental risks, continuing to transport water from Northern California through the Delta to other parts of the state is not a viable long-term option. So the choice comes down to diverting exports around the Delta or ending exports and making do with other supplies in regions currently relying on exports.

Although ending exports would provide significant tangible benefits (both direct and indirect) for desirable fish, this strategy would be particularly expensive to the state's economy. It would also likely increase the difficulty of raising the financial resources necessary for environmental investments in the Delta.

A peripheral canal would provide significant benefits to the regions relying on exports. In addition to water supply and quality benefits for urban users, there are potentially important benefits to agriculture and the environment. Reducing the salinity of water exported for agriculture might greatly extend the economic life of agriculture in the southern Central Valley and should eventually provide some improvement in San Joaquin River salinity. If properly managed, a canal could significantly improve conditions for desirable Delta fish relative to the present export system.

Compared with a peripheral canal, dual conveyance does not offer much added environmental promise, but it can help maintain water quality for farmers in the southern Delta under modest levels of sea level rise and will likely be a necessary interim solution. In the very near term, some investments should continue to maintain the deteriorating through-Delta system as the transition is made to either ending exports or building a peripheral canal. The weaker environmental performance of a peripheral canal compared with ending exports might be usefully mitigated by employing some of the economic surplus generated by the canal to enhance ecosystem investments.

### ***Governance, Regulation, and Finance***

A successful Delta solution will require governance, regulatory, and financial mechanisms and institutions that allow firm decisions to be made

in a timely way. This institutional framework must include contributions, involvement, and responsibility of water export users and also should include upstream diverters (who remove almost twice the amount of Delta outflows as export users) under a broader statewide authority.

12. **To be viable, a peripheral canal or dual conveyance would require effective governance, regulatory, and financing mechanisms.** By making it possible to divert water around the Delta, a canal creates opportunities for environmental and economic benefit, but it also raises new institutional challenges. One issue is whether to provide safeguards for the environment and other water users by limiting the size of the canal or devising an iron-clad governance system. A second is financing: Even if export users agree to pay for the canal—as they have indicated they would—funds must be raised for ecosystem investments and to mitigate harm to Delta farms whose water quality conditions could deteriorate more quickly with a canal. A third is whether the regulatory system can be adapted to the new and changing conditions.
13. **Governance mechanisms can be devised to provide appropriate safeguards for a peripheral canal.** Northern California’s concerns that a canal would export too much water from the region can be met by setting long-term maximum export levels, enforced by regulations and law, surcharge fees, or capacity ownership. Environmental safeguards for adequate instream flows can be provided by allocating a share of capacity to the environment, which can be used as needed or leased to fund restoration efforts. With such safeguards, it should be possible to build a canal large enough to take advantage of tidal flows and California’s variable hydrology for both environmental and economic purposes.
14. **Financing mechanisms are available to cover the range of water system needs.** The precedent of having export users pay for their own infrastructure costs is well established with the State Water Project, and this should be extended to any new conveyance facility. Because export users will benefit directly from more reliable and higher-quality water, and because exports will continue to cause some environmental problems, it is appropriate for users of a peripheral canal to pay an eco-

surcharge on export volumes. Because the water quality cost savings of a peripheral canal are substantial, it is appropriate to allocate at least some of these savings to environmental programs. Upstream diverters, who currently account for nearly two-thirds of all withdrawals from the Delta watershed, should also be expected to financially support ecosystem programs. Ecosystem finance would also benefit from the ability to lease shares of conveyance capacity. Finally, some public funds may be appropriate to supplement these sources and to help cover mitigation costs for in-Delta users, although such funds are unlikely to be plentiful given the long-term financial problems of state and federal governments.

15. **The regulatory framework is not prepared to oversee the Delta of the future.** Neither the Clean Water Act (1972) nor the Endangered Species Act (1973) acknowledges the effects of climate change, a key driver of future Delta conditions. Under the terms of the Clean Water Act, it may be difficult to take proactive steps to protect Delta exports from encroaching salinity and to increase habitat variability by building a peripheral canal, because this may hasten the natural decline of water quality for some Delta farmers. The Endangered Species Act could make it difficult to develop a reliable long-term habitat conservation plan for the Delta, given the risks of extinction for some species under a changing climate and the difficulty of disentangling the role of water exports from species decline.
16. **It makes both economic and environmental sense to involve upstream diverters, as well as users of exports, in sending more water to the Delta.** The reason a no exports alternative is preferable for Delta fish—in comparison with a peripheral canal—primarily rests on the assumption, based on considerable research, that reduced and altered flows into and out of the Delta are harmful to desirable fish. A direct restriction on exports is preferable to increased Delta outflow requirements only if the problem is the pumps themselves or resulting disruptions to fish, not the amount of water flowing out of the Delta. Reduced upstream diversions have an additional advantage of providing additional river flows from the point of reduced diversion all the way to the sea. Although the state has regulatory authority to impose cutbacks on upstream diverters, this is politically difficult

because they have more senior water rights. An alternative is to continue to impose the regulatory burden for higher Delta outflows on export users, as the more junior rights holders. Because the value of water use is higher in many export-related activities (including farming), export users will purchase some lower-value water from upstream users to meet the higher outflow requirement.

## Recommendations

The Delta of the future will be very different, and the costs of inaction are high. California needs to prepare for this changed future to direct it more favorably. A central step is to chart a new strategic direction for Delta water management, because many other decisions about Delta water and land management hinge on this choice. Planning environmental investments from the vantage point of a changing Delta, making strategic decisions about how to manage levee failures, and preparing for the future through governance and regulatory reforms are also essential.

### *Charting a Strategic Direction for Water Exports*

We recommend a planned transition away from through-Delta pumping to other export strategies, as summarized in Table 9.1. Continued through-Delta exports are already essentially unviable for the environment, and with time will become unviable economically. This transition will occur over time, with likely episodes of rapid change accompanying earthquakes, floods, and levee failures. A more expeditious transition would be less susceptible to natural disruptions. A strategic transition plan for water exports should have several elements.

1. **Adopt a strategy that employs a peripheral canal for long-term water management in the Delta.** Properly implemented, an interim dual intake, and ultimately a peripheral canal, presents the best prospects for meeting co-equal long-term environmental and economic objectives. Although many technical and policy details need to be worked out before actually building and operating a canal, not everything needs to be resolved before making a strategic decision. The key issues that must be resolved in the short term are the governance mechanism (to provide adequate safeguards for the

- environment and other water users) and the financing scheme (to protect taxpayers and ensure that environmental costs are covered).
2. **Ensure up-front commitments from export water users to pay for a peripheral canal.** To reduce the burden on statewide financial obligations and maintain proper financial incentives, export users should pay for this infrastructure, its operations, and its regulation.
  3. **To improve environmental and water supply performance, seek safeguards on the operation of a peripheral canal through governance institutions rather than through limits on the physical capacity of the canal.** Since a dual conveyance system can be only an interim option, the long-run costs of building an artificially small canal are high. Current efforts to examine a canal alternative should flesh out ways to provide iron-clad institutional safeguards through the allocation of shares in conveyance capacity to an environmental water trust. Safeguards for areas of origin should be provided through long-term average export limits rather than physical limits on the canal. Imposing export limits based primarily on physical size reduces the ability of a peripheral canal to operate flexibly to minimize environmental harm over tidal and seasonal cycles. Important physical capacity limits already exist downstream of the Delta.
  4. **Require both export water users and upstream diverters to contribute funds and water to improving the Delta ecosystem.** Export and upstream water users share responsibility for ecosystem decline in the Delta. With a peripheral canal, export users will receive large financial gains from improved water quality and a more reliable water supply, and they should be expected to direct some of these benefits to the environment. But upstream water users should also contribute to Delta recovery because their diversions both reduce and alter freshwater flow patterns available for fish. Upstream water users also will benefit from improved water marketing opportunities south of the Delta with a successful peripheral canal. If political realities require that the regulatory burden remain with export water users, as the more junior rights holders, the state should facilitate long-term water marketing arrangements with upstream diverters.



## *Preparing for the Changing Delta Ecosystem*

California should actively prepare for a changing Delta ecosystem. This includes planning for sea level rise, climate warming, permanent levee failures, and new invasive species. A rigidly negotiated plan is unlikely to succeed and experimentation and detailed modeling studies will be needed to inform a decision-capable governing framework.

5. **Consider the changing nature of the Delta in ecosystem planning.** Inevitable changes in the Delta include more aquatic habitat, more variation in salinity both temporally and spatially, likely higher water temperatures, as well as future invasions of exotic species. Some of these changes, such as more open-water habitat, may benefit desirable Delta fish species, whereas others, such as rising temperature and alien species, pose constraints. To build a sound habitat conservation planning framework, there is a need to prioritize which ecosystem attributes should be the goals of management in the future Delta.
6. **Do not manage the Delta for single species.** There are many threatened and potentially threatened native species in the Delta, including organisms besides fish. Managing for one species alone (e.g., delta smelt or Chinook salmon) is neither feasible nor in the long-term interests of other desirable species. A forward-looking approach to managing the habitat of multiple species, such as that required by the Natural Communities Conservation Planning (NCCP) Act, provides the best potential for developing a durable habitat conservation plan for the Delta.
7. **Develop an experimental ecosystem restoration program.** There is an urgent need to test ideas and long-standing assumptions about how the ecosystem functions to enhance or create more favorable and variable habitat for desirable fish. Particularly promising areas for experimentation are along the fringes of the Delta, including Suisun Marsh, the Cache-Slough/Liberty Island region, and Yolo Bypass (see Appendix D for details):
  - Suisun Marsh: Planning should begin immediately to accommodate the conversion of this area into extensive brackish water habitat as the result of sea level rise. Areas most likely to be inundated in the near future should be assessed to determine (1) if levees should be repaired

and areas resuscitated, (2) the potential for experimental studies such as artificial levee breaches, and (3) which monitoring studies are needed. With these findings in hand, a study should begin to evaluate the effects of inundation on desirable species.

- Cache Slough-Liberty Island: A comprehensive plan of action should be developed and implemented to foster the development of tidal freshwater habitat that favors such species as delta smelt and Chinook salmon.
  - Yolo Bypass: Annual flooding of some additional areas in the Bypass (along the Tule Canal and Toe Drain) would create more opportune conditions for salmon rearing and splittail spawning. To this end, a deep gate should be constructed on the Fremont Weir to allow water into the Bypass at lower flows of the Sacramento River than currently occur.
8. **Include flooding Delta islands in ecosystem experimentation.** To learn how to manage future island failures for desirable fish and other aquatic species, at least one island should be selected to study the short-term effects of levee breaching and island flooding. Longer-term studies should document how fish and invertebrate (fish food) abundance changes over time on the flooded island. The State Water Resources Control Board and various state and federal fisheries agencies need to develop a regulatory environment that will allow such experimental flooding. In addition, a rapid-response team should be appointed and funded to study the effects of breaches that will occur naturally.
9. **Address sea level rise and permanently flooded islands in hydrodynamic modeling.** The Delta's ecosystem and water supplies are driven significantly by the physical nature of the Delta and how it changes with tides, sea level rise, and geomorphology (such as permanent island failures and breaches). New hydrodynamic and water quality modeling capabilities are needed for managing the Delta of the future and better preparing for and understanding the consequences of changes in the Delta's ecosystem. Greater use of 3-D modeling and translation to faster-running 2-D and 1-D models will be required. Better representation of the speed of flows and other water quality characteristics also will be needed. Improved

understanding of island flooding and sea level rise must be developed *before* these events occur; waiting until after field data become available will be too late for many proactive activities.

### ***Managing Delta Levees and Land Use***

California should move away from levees as the primary means of managing Delta land and water.

10. **Prepare for island failures in the Delta.** The traditional response to island failures is for the state to step in and repair and restore them, regardless of statewide interests. This policy should be replaced by one that restores islands only if this is cost-effective from a statewide perspective and beyond the capabilities of local levee districts. In the interests of coherent state policy, financial prudence, and managing landowner expectations, such a determination should be established before islands fail.
11. **Continue major Delta levee improvements only for those islands that have a cost-effective statewide interest.** These islands will be those that protect transportation and energy infrastructure or are important for interim water exports. Some islands, such as those in the western Delta, may require short-term investments in levee improvements while alternatives to through-Delta exports are developed.
12. **Devise mitigation strategies for some Delta landowners.** Current Delta land and water users will be affected by major changes in state policy regarding the Delta, even if change is overdue and should have been anticipated. Some financial compensation to ease the transition of Delta agriculture is warranted. Such a program should be developed now, and it should provide incentives for Delta landowners to sign up early.

### ***Making Decisions and Regulating the New Delta***

A new framework for governance and regulation is needed for the new Delta. To increase the chances of favorable ecosystem and economic outcomes as the Delta transitions, California needs a policymaking environment that enables decisionmakers to anticipate the changes ahead.

This will require three ingredients: effective political leadership, a sound governance system, and an appropriate set of regulatory tools.

13. **California’s leaders will need to chart a new course for the Delta.** Experience suggests that it is unreasonable to expect the Delta’s many stakeholders to come to consensus solutions in a timely way or to reach decisions that are in the broader statewide interest. Major policy decisions must be made at a higher level to help chart a new course for Delta management and negotiate solutions to some of the difficult tradeoffs facing those who use Delta resources. Important decisions include how to manage water exports and how to provide durable funding solutions to support the Delta ecosystem. Direction on new Delta governance and regulations must come from California’s governor and legislature, with the involvement of federal and local agencies.
14. **Keep Delta governance issues on the front burner.** In this report, we have focused principally on one new governance issue—the management of conveyance capacity with safeguards for non-export water users. The Delta faces numerous other governance concerns, including improving oversight of regional land resources and the process for balancing human uses with ecosystem needs. Several efforts have begun to assess the options available, of which there are many, including models such as the Coastal Commission, the Coastal Conservancy, and the Tahoe Regional Planning Authority. These efforts are as important as the technical work to lay out options for water management in the Delta.
15. **Anticipate needed regulatory changes.** To make the best of a changing Delta, California needs to start dealing now with a regulatory system that is more reactive than proactive and that does not account for the effects of changing natural conditions induced by climate change and other factors. Regardless of which approach is taken for long-term water exports, a systematic review of regulatory issues relating to the Delta is needed. The state appears to be the most capable and responsible party to undertake such a review, perhaps aided by discussions with academics and stakeholders. We conclude this list of recommendations with two key Delta regulatory issues.

16. **Start dealing now with the regulatory consequences of sea level rise and island failures.** Sea level rise, the needs of Delta fish species, and water quality and reliability concerns for water export users all push in the direction of more variable Delta salinity, which can be better for fish but could preclude some present in-Delta water uses. The State Water Resources Control Board will need to work with federal officials to see how California can make the necessary changes in water quality regulations, while remaining in compliance with federal law. Whether or not it is legally required, mitigation to Delta farmers for the loss of water quality may be a useful tool in reaching an acceptable solution. The state also needs to develop a policy for handling potential liabilities from island flooding on neighboring islands. For Delta levees that are part of federally authorized flood projects, proactive discussions about levee repair alternatives must be held with the U.S. Army Corps of Engineers.
17. **Assess options for making the habitat conservation planning framework compatible with changing Delta conditions.** The habitat conservation planning process for the Delta that is now under way could be compromised if it fails to adequately consider the changes occurring in this region. The export projects will likely be open to Endangered Species Act challenges (and cutbacks) if the protected species do not do well, and if there is some chance that exports play a role. These risks will increase with climate change and the associated rise in water temperatures. California will need to work with federal authorities to find ways to not automatically consider a conservation plan a failure—potentially halting the associated project—if a listed species is lost to climate-related factors or other external events, such as invasive species. In the meantime, water export users will need to factor into their analysis of alternatives the risks of species nonrecovery and the associated cuts in exports.

## Charting the Future for a Changing Delta

The ongoing and increasingly rapid changes in the Delta pose a long-term challenge to California as a whole, as well as to all parties involved in this perennial source of conflict. All parties seeking to achieve the Delta Vision's co-equal objectives of environmental sustainability and water supply

reliability have an interest in making a peripheral canal part of a long-term solution for the Delta. This strategy must be embedded in a comprehensive set of actions to improve aquatic environments in the Delta and the greater watersheds of the Sacramento and San Joaquin Rivers. To be viable, a long-term solution must include governance, regulatory, and financial arrangements to ensure that various goals are well served, including water supply, environmental management, and the state's local interests in the Delta. For a problem of such complexity and with innumerable stakeholders, it would be unusual and unexpected for local and regional stakeholders to negotiate such arrangements on their own in a timely way. Pursuit of a grand consensus solution for the Delta's many issues is likely only to continue the deteriorating status quo. Leadership from the governor and legislature is needed to create conditions for reasonable governance of the new Delta, with cooperation from local governments and federal agencies that regulate and manage water and land use.

# Guide to Online Technical Appendices

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## **A. Policy and Regulatory Challenges for the Delta of the Future**

Changes in the Delta will require or lead to major changes in Delta policy and regulation. Several aspects of Delta governance, regulation, and policy are explored.

## **B. Levee Decisions and Sustainability for the Delta**

The inexorable and irresistible drivers of the future of the Delta are reviewed: sea level rise, land subsidence, changing hydrology, and earthquakes. The consequences of these changes are examined in the context of economic decisions for upgrading or maintaining various Delta islands from a statewide perspective.

## **C. Delta Hydrodynamics and Water Salinity with Future Conditions**

The future hydrodynamics and water quality of the Delta are reviewed and examined under conditions of sea level rise and permanently failed islands. The water quality implications of various export strategies are explored for water export, environmental, and in-Delta uses.

## **D. Future of the Delta Ecosystem and Its Fish**

The future ecosystem of the Delta is discussed under conditions of sea level rise and permanent island failures. The viability of groups of fish under changed conditions is explored, with associated management and policy implications.

## **E. Expert Survey on the Viability of Delta Fish Populations**

The results of a survey of 39 experts on the Delta ecosystem are presented concerning the likely success of improving the viability of fish species. Various alternative export and other water management actions are compared.

## **F. Economic Costs and Adaptations for Alternative Delta Regulations**

Model results are used to estimate the economic costs and water management adaptations from long-term reductions in exports and increases in Delta outflow requirements. These results offer an integrated perspective on the Delta's role in statewide water supply and management.

## **G. Peripheral Canal Design and Implementation Options**

If there is a decision to build a peripheral canal as part of a long-term Delta solution, many additional decisions will be required. The variety of subsequent decisions is presented and briefly discussed.

## **H. Delta Drinking Water Quality and Treatment Costs**

The additional drinking water treatment costs of using water from the Delta are estimated and compared with treatment costs for water drawn from the Sacramento River upstream of the Delta. These costs are estimated for present conditions, as well as with sea level rise and the permanent failure of some islands.

## **I. Economic Effects on Agriculture of Water Export Salinity South of the Delta**

The losses of agricultural revenues to farms in the southern Central Valley related to the salinity of export water are estimated for the year 2030. Reductions in these economic losses are estimated for several export alternatives.



## **J. Decision Analysis of Delta Strategies**

A formal economic and fish viability decision analysis is made of the Delta export management alternatives. The decision analysis allows for explicit analysis of uncertainties regarding fish recovery, sea level rise, and extensive levee failures as well as implicit incorporation of other uncertainties.



# References

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- Aitchison, Danae, “Institutional Options for Delta Vision Governance,” letter to John Kirlin, Attorney General’s Office, Sacramento, California, October 15, 2007, available at <http://deltavision.ca.gov>.
- Atwater, B. F., S. G. Conard, J. N. Dowden, C. W. Hedel, R. L. Donald, and W. Savage, “History, Landforms, and Vegetation of the Estuary’s Tidal Marshes,” in T. J. Conomos, A. E. Leviton, and M. Berson, eds., *San Francisco Bay: The Urbanized Estuary*, AAAS, Pacific Division, San Francisco, California, 1979, pp. 347–385.
- Baptist, M. J., V. Babovic, J. Rodriguez Uthurburu, R. E. Uittenbogaard, A. Mynett, and A. Verwey, “On Inducing Equations for Vegetation Resistance,” *J. of Hydraulic Research*, Vol. 45, No. 4, 2007, pp. 435–45
- Barnett, T. D., et al., “Human-Induced Changes in the Hydrology of the Western United States,” *Science*, Vol. 319, 2008, pp. 1080–1083.
- Berkes, F., and C. Folke, *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience*, Cambridge University Press, Cambridge, United Kingdom, 1998.
- Bureau, J. R., “DRERIP Hydrodynamic/Transport Conceptual Model,” draft report, December 20, 2007.
- Cayan, D. R., E. P. Maurer, M. D. Dettinger, M. Tyree, and K. Hayoe, “Climate Change Scenarios for the California Region,” *Climatic Change*, Vol. 87 (Suppl. 1), 2008b, pp. S21–S42.
- Cayan, D. R., P. D. Bromirski, K. Hayhoe, M. Tyree, M. D. Dettinger, and R. E. Flick, “Climate Change Projections of Sea Level Extremes Along the California Coast,” *Climatic Change*, Vol. 87 (Suppl. 1), 2008a, pp. S57–S73.
- Church J. A., and N. J. White “Twentieth Century Acceleration in Sea Level Rise,” *Geophysical Research Letters*, Vol. 33, LO1602, 2006.
- Delta Risk Management Strategy Program of the Department of Water Resources, 2007, available at <http://www.drms.water.ca.gov/>.
- Division of Water Resources, *State Water Plan*, Bulletin 25, California Department of Public Works, Sacramento, California, 1930.

- Department of Water Resources, *California Water Plan*, Bulletin No. 3, California, May 1957.
- Department of Water Resources, *Sacramento–San Joaquin Delta Water Atlas*, Sacramento, California, 1995.
- Department of Water Resources, “Delta Levees Program Components,” Web page, 2007a, available at <http://www.dfm.water.ca.gov/dsmo/levees/components.html>.
- Department of Water Resources, “DWR Releases Water Delivery Impact Estimates Following Wanger Decision,” Advisory, Sacramento, California, December 24, 2007b.
- Department of Water Resources, “An Initial Assessment of Dual Delta Water Conveyance,” prepared for the Delta Vision Blue Ribbon Task Force, Sacramento, California, April 2008.
- Deverel., S., “Technical Memorandum: Delta Risk Management Strategy (DRMS) Phase 1, Topical Area: Subsidence,” 2007, available at <http://www.drms.water.ca.gov/Updated2007/>.
- Draper, A. J., M. W. Jenkins, K. W. Kirby, J. R. Lund, and R. E. Howitt, “Economic-Engineering Optimization for California Water Management,” *Journal of Water Resources Planning and Management*, Vol. 129, No. 3, May 2003, pp. 155–164.
- Florsheim, J. L., and M. D. Dettinger, “Climate and Floods Still Govern California Levee Breaks,” *Geophysical Research Letters*, Vol. 34, L22403, 2007.
- Folke, C., S. Carpenter, B. Walker, M. Scheffer, T. Elmquist, L. Gunderson, and C. S. Holling, “Regime Shifts, Resilience, and Biodiversity in Ecosystem Management,” *Annual Reviews in Ecology and Systematics*, Vol. 35, 2004, pp. 557–581.
- Gross, E. S., M. L. MacWilliams, and N. Nidzieko, “Three-Dimensional Salinity Simulations of Sea Level Rise Scenarios,” Delta Risk Management Strategy, Department of Water Resources, Sacramento, California, 2007.
- Gunderson, L. H., and C. S. Holling, eds., *Panarchy: Understanding Transformation in Human and Natural Systems*, Island Press, Washington, D.C., 2001.

- Hanak, Ellen, *Who Should Be Allowed to Sell Water in California? Third Party Issues and the Water Market*, Public Policy Institute of California, San Francisco, California, 2003.
- Hundley, Norris, Jr., *The Great Thirst. Californians and Water: A History*, Revised Edition, University of California Press, Berkeley, California, 2001.
- Intergovernmental Panel on Climate Change, *Climate Change 2007: Synthesis Report*. Contribution of Working Groups I, II and III to the Fourth Assessment, Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp., 2007.
- Isenberg, P., M. Florian, R. M. Frank, T. McKernan, S. W. McPeak, W. K. Reilly, and R. Seed, “Blue Ribbon Task Force Delta Vision: Our Vision for the California Delta,” State of California Resources Agency, Sacramento, California, January 2008.
- Jackson, W. T., and A. M. Paterson, *The Sacramento–San Joaquin Delta and the Evolution and Implementation of Water Policy: An Historical Perspective*, California Water Resources Center, Contribution No. 163, University of California, Davis, June 1977.
- Jenkins, M. W., J. R. Lund, R. E. Howitt, A. J. Draper, S. M. Msangi, S. K. Tanaka, R. S. Ritzema, and G. F. Marques, “Optimization of California’s Water System: Results and Insights,” *Journal of Water Resources Planning and Management*, Vol. 130, No. 4, July 2004, pp. 271–280.
- Kelley, R., *Battling the Inland Sea*, University of California Press, Berkeley, California, 1989.
- Krone, R. B., “Sedimentation in the San Francisco Bay System,” in T. J. Conomos, A. E. Leviton, and M. Berson, eds., *San Francisco Bay: The Urbanized Estuary*, AAAS, Pacific Division, San Francisco, California, 1979, pp. 85–96.
- Liu, J., D. Thomas, S. Carpenter, C. Folke, M. Alberti, C. Redman, S. Schneider, E. Ostrom, A. Pell, J. Lubchenco, W. Taylor, A. Ouyang, P. Deadman, T. Kratz, and W. Provencher, “Coupled Human and Natural Systems,” *Ambio*, Vol. 36, No. 8, 2007, pp. 639–649.

- Logan, S. H., *An Economic Analysis of Flood Control Policy in the Sacramento–San Joaquin Delta*, Contribution 199, California Water Resources Center, Davis, California, June 1989.
- Logan, S. H., “Global Warming and the Sacramento–San Joaquin Delta,” *California Agriculture*, Vol. 44, No. 3, 1990a, pp. 16–18.
- Logan, S. H., “Simulating Costs of Flooding under Alternative Policies for the Sacramento–San Joaquin River Delta,” *Water Resources Research*, Vol. 26, No. 5, May 1990b, pp. 799–809.
- Ludwig, D., R. Hilborn, and C. Walters, “Uncertainty, Resource Exploitation, and Conservation: Lessons from History,” *Science*, Vol. 260, No. 5104, April 1993, pp. 17–36.
- Lund, J., E. Hanak, W. Fleenor, R. Howitt, J. Mount, and P. Moyle, *Envisioning Futures for the Sacramento–San Joaquin Delta*, Public Policy Institute of California, San Francisco, California, February 2007.
- Matthew, Raymond, *Variation and Control of Salinity in Sacramento–San Joaquin Delta and Upper San Francisco Bay*, Bulletin 27, Division of Water Resources, California Department of Public Works, Sacramento, California, 1931a.
- Matthew, Raymond, *Economic Aspects of a Salt Water Barrier Below the Confluence of Sacramento and San Joaquin Rivers*, Bulletin 28, Division of Water Resources, California Department of Public Works, Sacramento, California, 1931b.
- Maurer, E. P., “Uncertainty in Hydrologic Impacts of Climate Change in the Sierra Nevada Mountains, California under Two Emissions Scenarios,” *Climatic Change*, Vol. 82, 2007, pp. 309–325.
- Medellin-Azuara, J., J. J. Harou, M. A. Olivares, K. Madani-Larijani, J. R. Lund, R. E. Howitt, S. K. Tanaka, M. W. Jenkins, and T. Zhu, “Adaptability and Adaptations of California’s Water Supply System to Dry Climate Warming,” *Climatic Change*, Vol. 87 (Suppl.1), March 2008, pp. S75–S90.
- Mount, J. F., and R. Twiss, “Subsidence, Sea Level Rise, Seismicity in the Sacramento–San Joaquin Delta,” *San Francisco Estuary and Watershed Science*, Vol. . 3, Article 5, 2005, available at: <http://repositories.cdlib.org/jmie/sfew/vol3/iss1/art5>.

- Mount, J., CALFED Independent Science board, letter to Michael Healy, Lead Scientist, CALFED Bay-Delta Program, "Sea Level Rise and Delta Planning," September 6, 2007, available at [http://calwater.ca.gov/science/pdf/isb/meeting\\_082807/ISB\\_response\\_to\\_ls\\_sea\\_level\\_090707.pdf](http://calwater.ca.gov/science/pdf/isb/meeting_082807/ISB_response_to_ls_sea_level_090707.pdf).
- Moyle, P. B., "The Future of Fish in Response to Large-Scale Change in the San Francisco Estuary, California," in K.D. McLaughlin, editor, *Mitigating Impacts of Natural Hazards on Fishery Ecosystems*, American Fishery Society, Symposium 64, Bethesda, Md., 2008.
- Natural Heritage Institute, "Concept Offered for Consideration by BDCP Implementation Structure/Governance Work Group," San Francisco, California, April 16, 2008.
- Null, S., and J. R. Lund, "Re-Assembling Hetch Hetchy: Water Supply Implications of Removing O'Shaughnessy Dam," *Journal of the American Water Resources Association*, Vol. 42, No. 4, April 2006, pp. 395–408.
- Orlob, G. T., "An Alternative to the Peripheral Canal," *Journal of the Water Resources Planning and Management Division*, ASCE, Vol. 108, No. WR1, March 1982, pp. 123–141.
- Orlob, G.T., "San Joaquin Salt Balance: Future Prospects and Possible Solutions," in A. Dinar and D. Zilberman, eds., *The Economics and Management of Water and Drainage in Agriculture*, Kluwer, Boston, Massachusetts, 1991, pp. 143–167.
- Owen, D., "Law, Environmental Dynamism, Reliability: The Rise and Fall of CALFED," *Environmental Law*, Vol. 77, 2007, pp. 1145–1215.
- Pulido-Velázquez, M., M. W. Jenkins, and J. R. Lund, "Economic Values for Conjunctive Use and Water Banking in Southern California," *Water Resources Research*, Vol. 40, No. 3, March 2004.
- Rosenzweig, M., *Win-win Ecology*, New York: Oxford University Press, 2002.
- Scheffer, M., and S. R. Carpenter, "Catastrophic Regime Shifts in Ecosystems: Linking Theory to Observation," *Trends in Ecology and Evolution*, Vol. 18, 2003, pp. 648–656.
- Scheffer, M., S. Carpenter, J. A. Foley, C. Folkes, and B. Walker, "Catastrophic Shifts in Ecosystems," *Nature*, Vol. 413, 2001, pp. 591–596.

- Schoups, G., "Regional-Scale Hydrologic Modeling of Subsurface Water Flow and Reactive Salt Transport in the Western San Joaquin Valley, California," Dissertation, University of California, Davis, 2004.
- State Water Resources Control Board, *Final Environmental Impact Report for Implementation of the 1995 Bay/Delta Water Quality Control Plan*, SWRBC Bay Delta Program, Sacramento, California, November 1999.
- State Water Resources Control Board, *Revised Water Right Decision D-1641*, Sacramento, Calif.: California Environmental Protection Agency, March 15, 2000, available at: <http://www.waterrights.ca.gov/Decisions/D1641revs.pdf>.
- Stewart, I., D. R. Cayan, and M. D. Dettinger, "Changes in Snowmelt Runoff Timing in Western North America under a 'Business as Usual' Climate Change Scenario," *Climatic Change*, Vol. 62, 2004, pp. 217–232.
- Tanaka, S. K., and J. R. Lund, "Effects of Increased Delta Exports on Sacramento Valley's Economy and Water Management," *Journal of the American Water Resources Association*, Vol. 39, No. 6, December 2003, pp. 1509–1519.
- Tanaka, S. K., T. Zhu, J. R. Lund, R. E. Howitt, M. W. Jenkins, M. A. Pulido, M. Tauber, R. S. Ritzema, and I. C. Ferreira, "Climate Warming and Water Management Adaptation for California," *Climatic Change*, Vol. 76, No. 3-4, June 2006.
- Torres, R. A., et al., *Seismic Vulnerability of the Sacramento–San Joaquin Delta Levees*, report of the Levees and Channels Technical Team, Seismic Vulnerability Sub-Team, to the CALFED Bay-Delta Program, Sacramento, California, 2000.
- URS Corporation and Jack R. Benjamin and Associates, Inc., Technical Memorandum, Topical Area: Water Analysis Module, prepared for the California Department of Water Resources, 2007a.
- URS Corporation and Jack R. Benjamin and Associates, Inc., Delta Risk Management Strategy (DRMS) Phase 1 Risk Analysis Report, draft, prepared for the California Department of Water Resources, 2007b.
- U.S. Geological Survey, "Bay Area Earthquake Probabilities," n.d., available at <http://quake.usgs.gov/research/seismology/wg02/>.
- Walker B. and D. Salt. 2006. *Resilience Thinking: Sustaining Ecosystems and People in a Changing World*. Island Press, Washington, D.C.



Whitney, Victoria, Deputy Director for Water Rights, State Water Resources Control Board, presentation to the Delta Vision Blue Ribbon Task Force, January 31, 2008, available at <http://deltavision.ca.gov/>.



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