8. Evaluating Delta Alternatives

"The true rule, in determining to embrace, or reject any thing, is not whether it have any evil in it; but whether it have more of evil, than of good. There are few things wholly evil, or wholly good. Almost every thing, especially of governmental policy, is an inseparable compound of the two; so that our best judgment of the preponderance between them is continually demanded."

Abraham Lincoln

As we saw in Chapter 2, early studies of the Delta sought solutions to meet a relatively narrow set of objectives: improving freshwater supply and reliability for water users within and south of the Delta; reducing Delta salinity to limit infestations of a marine borer, *Teredo*, which threatened wooden docks and structures; and improving navigation. Early environmental concerns were limited largely to fish passage and pollution from sewage. But the stability and strength of island levees have been a continuous concern, as have the costs of Delta management alternatives and the question of who should pay for them (Jackson and Paterson, 1977).

Today, California has an economy and society that could have only been dreamed of at the time of the earliest Delta studies. Although we retain many of the same concerns for the Delta, there have been changes in emphasis. New technology and infrastructure have eliminated the need to manage *Teredo* infestations (San Francisco Bay's first invasive species problem), but other alien invaders pose serious threats to California ecosystems, and society now places a higher value on maintaining a variety of aquatic and terrestrial species that depend on Delta habitats. In addition, greater reliance on the Delta for water supply and increased urbanization have heightened concerns about Delta water quality and about the weak levees that surround many Delta islands.

Some of these concerns will continue to evolve as a result of changing conditions in the Delta. As described in Chapter 3, increasing sea level rise, continued land subsidence, regional climate change, and increasing urbanization all contribute to the unsustainability of current Delta management. As California's population continues to grow, it is also likely that society will increasingly emphasize Delta services, including fish and wildlife habitat, recreation, urban housing, and water quality, making the Delta an even more important resource than it is today.

Any long-term management alternative for the Delta should be evaluated by its ability to address a broad range of concerns. In this chapter, we perform an initial evaluation of the nine alternatives described in Chapter 7. We first examine how responsive each alternative is to key Delta problems and concerns. We then evaluate, as best we can, how well different alternatives are likely to perform in terms of these concerns. Our aim is not to pinpoint "the" optimal solution but rather to identify several broad Delta alternatives with the most promise. Our analysis also serves to highlight the need for in-depth evaluation of the details of any Delta alternative before Californians make lasting policy decisions on the Delta's future.

Evaluation of Strategic Directions

A simple way to begin is to identify the major Delta issues that any alternative must address and to note how many of these issues each alternative is able to handle (Table 8.1). We have highlighted six issues likely to be important for key Delta interests:

- **Island flooding.** Does the alternative address long-term risks to Delta water supply, water quality, and land use from island flooding?
- **Water export quality.** Does the alternative provide a way to maintain or improve the quality of water exported to users south and west of the Delta?
- **In-Delta water quality for agricultural and urban users.** Would the alternative keep salinity levels sufficiently low to permit irrigation and urban water uses in at least parts of the Delta?
- **Water supply reliability.** Does the alternative provide a way to enhance the reliability of water supplies for Delta exporters?
- **Desirable species.** Does the alternative improve conditions for desirable fish and terrestrial species that depend on the Delta?
- **Urbanization.** Does the alternative provide sufficiently high levels of flood protection (exceeding 200-year average recurrence) and water quality to support urbanization in some parts of the Delta?

Table 8.1

Problems Addressed by Evaluated Alternatives

Alternatives	Island Flooding	Water Export Quality	In-Delta Water Quality	Water Supply Reliability	Habitats Supporting Desirable Species	Urbanization in the Delta
Freshwater Delta						
1. Levees as Usual	?					
2. Fortress Delta	X	X	X	X		X
3. Seaward Saltwater Barrier		X	X	X		
Fluctuating Delta						
4. Peripheral Canal Plus	X	X	?	X	?	?
5. South Delta Restoration Aqueduct	X	X	X	X	?	?
6. Armored-Island Aqueduct	X	X	X	X	?	X
Reduced-Exports Delta						
7. Opportunistic Delta	X	?	?	?	X	?
8. Eco-Delta	X	?	?	?	X	
9. Abandoned Delta	X				?	

NOTES: "X" indicates that the problem is addressed by the alternative; "?" means that it might be addressed, depending on details; cells left blank indicate that the alternative does not effectively address the problem.

In selecting these issues, we acknowledge that none of the alternatives will be able to address all of them entirely. In particular, we do not consider it feasible to eliminate or substantially reduce the risk of flooding for all Delta islands. Over the long term, some agricultural land will therefore go out of production. In our analysis, the key criterion for the feasibility of Delta agriculture is the extent to which an alternative provides adequate in-Delta water quality to maintain profitability on islands that do not flood.

Some alternatives respond to only a few concerns, whereas others respond to a wider range of problems. The Freshwater Delta alternatives do not look particularly promising in terms of their scope. If not combined with other alternatives, the Levees as Usual option (#1) looks particularly poor from all perspectives, because it is not designed to address any major problem over the long term. The Seaward Saltwater Barrier alternative (#3) also looks unpromising, because it is unable to solve many contemporary problems: It does not address environmental concerns and it makes urbanization more difficult. In effect, although it eliminates the need to maintain islands to keep the Delta fresh, it could increase flood risks.[1] Although the Fortress Delta alternative (#2) better protects many Delta islands, it, too, is unable to address environmental issues in the Delta. The maintenance of a freshwater system in the Delta does not permit the restoration of fluctuating salinity, which would facilitate the control of invasive species now threatening the survival of some key species.

All three of the Fluctuating Delta alternatives appear to have the potential to address most, and perhaps all, of the problems identified. For the two alternatives that contain versions of the peripheral canal, this potential depends on the details of canal design and implementation. Both canal versions address the risks of island flooding, in terms of water exports, by circumventing the Delta. The South Delta Restoration Aqueduct alternative (#5) also directly addresses water quality in the southern and eastern portions of the Delta. The ability of the Peripheral Canal Plus

[1] If a barrier is operated to keep water levels in the Delta higher than at present, it would worsen flooding risks, especially from spontaneous levee failures. For big flood events, it might perform a little better than other options, because it could reduce high tide effects for brief periods.

alternative (#4) to ensure water quality in the Delta, species protection, and urbanization depends on the extent to which complementary investments are made within the Delta. The compatibility of the South Delta Restoration Aqueduct alternative (#5) with some urbanization and with the restoration of delta smelt and other desirable species also depends on the details. The Armored-Island Aqueduct alternative (#6) is a type of through-Delta canal (rather than a peripheral one) but probably more porous on the east side and more fortified on the west side to allow managed salinity fluctuations to the west. It would tend to concentrate freshwater inflows in the eastern Delta and would fortify and protect some islands.

The Reduced-Exports alternatives—all of which are based on major changes in water export regimes—offer very different degrees of relief to Delta problems. As Chapter 6 indicates, users of Delta waters have some ability to adapt to changes in Delta exports, although the costs of certain adjustments are substantial. As we have envisioned it, the Opportunistic Delta alternative (#7) has the potential to address both ecosystem problems and the concerns of water exporters, but it anticipates a phase-out of some current land uses in at least parts of the Delta. The Eco-Delta alternative (#8) is essentially a variant of the Opportunistic Delta alternative that focuses on ecosystem needs. However, it offers the potential to satisfy some exporter concerns (both quality and supply reliability) as well as to address water quality concerns (particularly for environmentally friendly Delta agriculture). The Abandoned Delta alternative (#9) assumes a staged retreat from all Delta water and land uses, including environmental restoration. It therefore resolves the problem of island flooding by eliminating the need for Delta water supplies and economic land use. There could nevertheless be some ecosystem benefits to this alternative, resulting from its ability to increase salinity fluctuation in the western Delta and Suisun Marsh area.

Performance Criteria and Likely Performance

Of course, Table 8.1 does not indicate performance—or how well each issue would be addressed by each alternative. A major study of solutions for the Delta, drawing on a finite set of detailed performance criteria, would be needed to provide such an evaluation. In this initial evaluation, we take a much simpler approach. Using available information, we provide our best judgment on how well each alternative is likely to stack up across three broad criteria: environmental, water supply, and economic performance (Table 8.2). This analysis does not include the full range of current objectives for the Delta; there will inevitably be some controversy regarding any selection of evaluation criteria and estimation of performance. Nevertheless, this analysis offers some guidance on favorable directions to take. It also illustrates the type of comparative analysis that is desirable for long-term infrastructure decisionmaking. The following provides a brief outline of our three major performance criteria.

Environmental Performance

Under current law, environmental performance is an overriding concern for Delta management, because all users must consider the effects of their actions on endangered and threatened species. Our assessment of environmental performance is based on our judgment of how well each alternative could be adapted to improve the health of Delta-dependent desirable species; this evaluation is based on the understanding of the Delta ecosystem discussed in Chapter 4. One aspect of environmental performance is the entrainment of fish and fish larvae by export pumps. Available information is not sufficient to evaluate this problem thoroughly, but it is likely that any through-Delta alternative, as well as some peripheral canal alternatives, would need to include components to limit fish entrainment. A variety of options exist to mitigate this effect, including changing various intake locations, altering pumping patterns, and employing finer fish screens or bank filtration. Options are likely to vary in effectiveness and cost.

Water Supply

Our evaluation of water supply performance focuses on the ability of each alternative to provide water exports of sufficient quality to points south and west of the Delta. Table 8.2 summarizes this assessment in terms of volumes available in typical years. This evaluation draws on numerous water management studies, including the CALVIN model results presented in Chapter 6 and elsewhere (Jenkins et al., 2001, 2004; Lund et al., 2003; Tanaka and Lund, 2003; Tanaka et al., 2006; Medellin et al., 2006), and various results from the water resources simulation model (CALSIM) (Department of Water Resources, 2006; U.S. Bureau of Reclamation, 2005).[2] Although the different studies' methods and assumptions lead to a variety of results, they permit an assessment of the alternatives that seem most promising for water supply purposes. For water supply for agricultural and urban users within the Delta (a function of water quality in the Delta), we are currently unable to go beyond the qualitative assessment provided in Table 8.1.

Economic Performance

Economic performance relates to the diverse set of costs associated with each alternative. Costs include not only new investments and operating expenses but also the direct and secondary economic effects from changes in the availability of Delta land and water services. Investment costs may be incurred for new water supply facilities, improved levees to protect infrastructure and buildings from floods, gates, barriers, fish screens, and other infrastructure. Operating expenses arise from pumping, treatment, and maintenance costs as well as from levee repair and recovery costs from levee failures. Changes in service availability include costs from changes in water scarcity and reliability as well as from changes in water quality. As shown in Chapter 6, with foresight and preparation the California economy has significant potential to adjust, at some cost and institutional inconvenience, even to extreme policy changes in Delta exports. Land use transitions are also possible, including modifications of activities that now rely on current Delta levees. A key question is whether alternatives that seek to avoid major adjustment costs are preferable overall to those with major changes. Because these various costs would be borne by different groups and regions, questions of fairness will be an inevitable part of this policy discussion, in addition to the overall costs. Possible mitigating actions are discussed in Chapter 9.

Here, we provide some rough comparisons for illustrative purposes, focusing primarily on investment costs and adjustment costs for water users. An in-depth analysis of alternatives would need to consider a wider range of costs, including adjustment costs for users of other civil infrastructure and secondary economic effects. We estimate investment

[2]CALSIM is DWR's and USBR's model of CVP and SWP operations and deliveries. This model is widely used to evaluate water deliveries and operations of these major water projects.

Table 8.2

Comparisons of Likely Performance

Alternatives	Environmental Performance	Water Supply Exports	Economic and Financial Costs
Freshwater Delta			
1. Levees as Usual—current or increased effort	Unpredictable but, if present trends continue, poor	6+ maf/year short term; 0–6+ maf/year long term	~ $2 billion, plus increasing costs of failure and replacement
2. Fortress Delta (Dutch standards)	Poor, favors low productivity habitat mainly for alien species		> $4 billion
3. Seaward Saltwater Barrier	Creates a freshwater system favoring warm-water alien species	6+ maf/year long term	$2 billion–$3 billion
Fluctuating Delta			
4. Peripheral Canal Plus	Depends on configuration of canal but potentially allows more natural flow regime through Delta, favoring desirable fish	6+ maf/year long term	$2 billion–$3 billion; < $70 million/year additional water scarcity costs
5. South Delta Restoration Aqueduct	Provides a variety of habitats in South Delta; effect on desirable species depends on configuration and operation	6+ maf/year long term; lower export water quality than for Peripheral Canal Plus	$2 billion–$3 billion; < $41 million/year additional water scarcity costs
6. Armored-Island Aqueduct	Provides a variety of habitats but hard on anadromous fish (e.g., salmon)		$1 billion–$2 billion+; < $30 million/year additional water scarcity costs

Table 8.2 (continued)

Alternatives	Environmental Performance	Water Supply Exports	Economic and Financial Costs
Reduced-Exports Delta			
7. Opportunistic Delta	Provides opportunity for habitat diversity but could resemble Alternative #1	Highly variable, 2–8 maf/year	\$0.7 billion–\$2.2 billion in Delta and near Delta facilities; water scarcity cost < \$170 million/year
8. Eco-Delta	Good, because system managed to favor desirable species	Highly variable, probably 1–5 maf/year	Several billion dollars (eco-restoration only); + water user investments and water scarcity cost < \$600 million/year
9. Abandoned Delta	Probably poor, favoring alien species, similar to Alternative #1	0	~ \$500 million additional capital costs plus ~ \$1.2 billion/year scarcity and operating costs

NOTES: Unless specified, costs listed are for capital investments (see Appendix E). All alternatives except #9 (and possibly #2) would require additional investments for urban levees to provide flood protection exceeding 200-year average recurrence. All alternatives except #8 and #9 would require additional investments for ecosystem restoration. All alternatives foresee losses in Delta farm revenues, but these are included above only as part of water scarcity cost estimates for options #4 through #9. For options #1 to #3, there would be additional losses from land going out of production from island flooding. Adding finer fish screens or bank filtration to intakes to reduce fish and larvae entrainment would increase costs and potentially reduce pumping capabilities.

costs by using various published and unpublished sources and water user adjustment costs by drawing on the CALVIN and DAP results presented in Chapter 6. The Eco-Delta alternative is the only alternative that explicitly provides investment cost estimates for ecosystem restoration; these should be viewed as an upper bound on such investments, at least some of which would accompany some of the other scenarios. Because the trajectory of urbanization in the Delta may vary, we do not include the additional costs of urban levee fortification that would be necessary to accommodate such growth. These costs are likely to run in the range of $200 million to over $1.5 billion if 100–150 miles of levees must be upgraded for urban development. Additional levee costs might be incurred to protect civil infrastructure on interior islands. However, some levee investments in the Fortress Delta alternative could double as protection for urban areas and infrastructure, depending on the location of urban settlements and infrastructure networks relative to levees that need to be enhanced to protect Delta water supplies. Finally, we do not incorporate the costs of a mitigation program to ease adjustment for those bearing particularly high costs under the various alternatives (although for water users in the Delta, the estimated adjustment costs provide some indication). Detailed cost estimates for each alternative are discussed in Appendix E.

Summary Evaluation of Alternatives

Our judgment of the overall promise of each alternative appears in Table 8.3. Our analysis suggests alternatives that should be eliminated from further consideration and those that merit further exploration and refinement. The table also provides a thumbnail rationale for each of these judgments, which we expand on below.

Freshwater Delta Alternatives

On all counts, the three freshwater alternatives appear unpromising.

Perpetuating the Delta as a homogeneous freshwater body would be environmentally damaging. This strategy fosters the wrong kinds of habitat for native species and tends to promote undesirable invasive species.

Table 8.3

Summary Evaluation of Alternatives

Alternatives	Summary Evaluation	Rationale
Freshwater Delta		
1. Levees as Usual—current or increased effort	Eliminate	Current and foreseeable investments at best continue a risky situation; other "soft landing" approaches are more promising; not sustainable in any sense
2. Fortress Delta (Dutch standards)	Eliminate	Great expense; unable to resolve important ecosystem issues
3. Seaward Saltwater barrier	Eliminate	Great expense; profoundly undesirable ecosystem performance; water quality risks
Fluctuating Delta		
4. Peripheral Canal Plus	Consider	Environmental performance uncertain but promising; good water export reliability; large capital investment
5. South Delta Restoration Aqueduct	Consider	Environmental performance uncertain but more adaptable than Peripheral Canal Plus; water delivery promising for exports and in-Delta uses; large capital investment
6. Armored-Island Aqueduct	Consider	Environmental performance likely poor unless carefully designed; water delivery promising; large capital investment
Reduced-Exports Delta		
7. Opportunistic Delta	Consider	Expenses and risks shift to importing areas; relatively low capital investment; environmental effectiveness unclear
8. Eco-Delta	Consider	Initial costs likely to be very high; long-term benefits potentially high if Delta becomes park/open space/endangered species refuge
9. Abandoned Delta	Eliminate	Poor overall economic performance; southern Delta water quality problems; like Alternative #1, without benefits

Environmental performance would be worst with the Seaward Saltwater Barrier option, because it would also obstruct fish passage between the bay and the Delta.

Water supply performance would be good in the Fortress Delta and Seaward Saltwater Barrier alternatives—about 6+ maf per year of export deliveries (comparable to recent export levels). The exception is the Levees as Usual alternative, in which deliveries would be likely to decrease significantly as episodes of levee failure increase. Land subsidence and sea level rise make the Levees as Usual option increasingly unreliable and risky for water supplies. The Seaward Saltwater Barrier would be useful in maintaining a freshwater Delta after multiple island failures from a major earthquake and thus may be more dependable than other freshwater options in terms of water supply. But its structure and gate mechanisms would also be severely challenged by seismic events, when they are likely to be most needed.

Finally, the Freshwater Delta alternatives tend to be relatively expensive because all three are based on major levee or barrier investments. Investment costs for these options range from approximately $2 billion for Levees as Usual to over $4 billion for a Fortress Delta; costs for the Seaward Saltwater Barrier probably lie somewhere in between. Additional ongoing costs for levee maintenance and repair would be required for all these alternatives. Levees as Usual would have comparatively low initial capital costs but increasingly high costs of upkeep.[3] Costs for levee repair and levee failures would be particularly large and frequent. Additional failure recovery costs under this alternative could average on the order of $100 million per year.[4] The Fortress Delta alternative is likely to entail high investment costs as well as high ongoing maintenance and upkeep, given the increasing pressures of flood flows, sea level rise, and seismic risk that will face the Delta in the years ahead. However, failure recovery costs under this alternative could be considerably lower than those under Levees as Usual. Failure recovery costs also could be substantial for a Seaward Saltwater Barrier option, if Delta islands were maintained once the water supply risk had been eliminated.

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[3]For instance, DWR estimates that repairs to weakened or failed project levees currently cost on the order of $5,000 per foot ($28 million per mile).

[4]Estimated on the basis of a failure cost of roughly $10 billion, with a probability of failure of 1 percent per year. Such rough estimates could be refined using results from the ongoing DRMS. Even this relatively low estimate implies a present value of failure recovery costs of $2 billion (roughly the initial capital cost), and it does not include additional catastrophic event costs faced by state and local governments.

Overall, these solutions perform poorly environmentally, do not appear to offer cost-effective long-term solutions to water supply issues, and would be relatively expensive to carry out and maintain. We recommend eliminating all three of these alternatives from further consideration.

Fluctuating Delta Alternatives

Each of the Fluctuating Delta alternatives is promising for our three performance categories. Of course, the degree of favorable performance for any of these alternatives would depend greatly on the details of operation and implementation.

Environmentally, the Fluctuating Delta alternatives seek to break the dependency of the Delta on water exports. The Peripheral Canal Plus and the South Delta Restoration Aqueduct would do so by circumventing the Delta, whereas the Armored-Island Aqueduct would reconstruct through-Delta conveyance so that water export flows are largely isolated from the western part of the Delta, where salinity could fluctuate. These alternatives are likely to have good environmental performance, as they would provide a wide range of environmental habitats to support desirable species and offer greater patterns of fluctuation, which inhibit many potential and current invasive species. Their detailed environmental performances would differ with the particulars of each alternative.

Water supply export performance is also quite good for all three alternatives, with volumes in the range of 6+ maf per year. Exports are limited mostly by the capacity of downstream conveyance capacity and upstream water availability and depend much less on Delta conditions than at present, although enough fresh water would still need to flow into the Delta to maintain desired salinity fluctuations. Compared with the current through-Delta conveyance system, the Peripheral Canal Plus would enhance export water quality, because it avoids blending higher-quality Sacramento River water with the lower-quality water of the Delta. The reliability of these alternatives should be greater for floods, earthquakes, other Delta island failures, and many risks to water exports associated with protection of aquatic species.

Significant capital costs would be required for all three of these alternatives, although the costs presented here are highly uncertain. There would be some additional pumping costs for the Peripheral Canal Plus and

South Delta Restoration Aqueduct alternatives. Water scarcity costs would arise from lost agricultural production on some Delta islands, which would result from increased salinity levels necessary to support habitat favorable to desirable species. Given some likely improvement in water export reliability, water scarcity costs south and west of the Delta might decrease compared to current conditions but probably by no more than $20 million per year on average.

Fluctuating Delta alternatives would potentially improve the Delta's environment and its water export reliability and quality. The economic cost of each would be considerable but probably less than most of the freshwater alternatives. Perhaps most important, given the variety of changes facing the Delta, these alternatives tend to add flexibility to the system and to provide greater adaptability to changes in future conditions. We recommend that all three Fluctuating Delta alternatives be given further consideration.

Reduced-Exports Alternatives

The three Reduced-Exports alternatives rely on various modifications of Delta export pumping; our performance criteria indicate mixed potential.

The environmental performance of these options differs with the degree of pumping changes required to introduce greater habitat variability and specialization into the Delta. Of course, the details of environmental performance would differ with implementation details. It is interesting to note that abandoning the Delta, without any restoration actions, leads to a generally unfavorable long-term environmental condition similar to that of the Levees as Usual alternative. Any additional salinity fluctuation introduced here would be much less productive without other environmental restoration actions.

In the two alternatives in which water exports are curtailed rather than eliminated—the Opportunistic Delta and the Eco-Delta—exports would become more variable than they are currently. Although neither of these alternatives relies on significant new water supply infrastructure, investment costs remain substantial. Opportunistic pumping would probably be accompanied by some off-stream storage near the pumps to provide the flexibility to pump more water during high flow periods than can be accommodated by existing canal capacity. By contrast, the Abandoned

Delta has fairly low capital costs (mainly for strengthening interties) but very high operating and water scarcity costs.

Our evaluation of this set of alternatives finds that two merit further consideration. The Opportunistic Delta and the Eco-Delta—both of which encourage habitats supportive of desirable species in the Delta without constructing a peripheral or through-Delta canal—are worth considering further. Both provide the potential for better management of the Delta environment while permitting continued use of the Delta for other purposes, including water exports (albeit at reduced levels). By contrast, we do not consider it worthwhile to further consider the Abandoned Delta. The water supply and scarcity costs of this approach are unreasonably high and accompanied by likely serious salinity problems in the southern Delta as well as poor environmental performance for native species. Sea level rise and climate warming would likely accelerate the deterioration of the Delta if it were abandoned. And abandoning the Delta also reduces the environmental, land, and water resources available to California for adapting to climatic change, including the ability to move water to areas where it creates more economic well-being.

Desirable Characteristics of a Delta Solution

This analysis points to some of the characteristics that would be desirable to include in any Delta solutions.

Hybrid Solutions

To address most Delta problems, any comprehensive solution will need to contain a hybrid of several strategies. For example, a peripheral canal on its own might address some problems, but it leaves many others unaddressed. Likewise, levees will be an important part of any Delta solution, but levees alone are likely to be disastrous for some objectives and economically unreasonable overall. Although the recently passed bond measures provide valuable support to flood protection in the Delta, the mere funding of levee construction and reinforcement alone will be insufficient; more profound and integrated redesign of the system will be needed. Both in the comparison of the problem addressed by each alternative (Table 8.1) and in the summary evaluation of alternatives (Table 8.3), the more promising approaches tend to contain hybrid solutions.

"Soft Landing" for the Delta

A major motivation for changing management of the Delta is the increasingly fragile nature of the current Delta's environmental, land use, and water supply functions. There is an unacceptable probability that the Delta's current management and services could abruptly crash in ways that would be catastrophic environmentally and economically. Most of the alternatives considered here seek a soft landing from the Delta's current severe disequilibrium and vulnerability. Efforts to address short-term emergencies and failures in the near term are necessary (as the DRMS is attempting to explore), but longer-term efforts should be dedicated to preventing such failures and catastrophes and should significantly alter the Delta from its increasingly unsustainable form.

Trial Solutions

Broadly obvious and ideal solutions do not exist for the Delta's problems. All promising solutions entail significant uncertainties. The implementation of any promising solution should involve some experimentation before making irreversible decisions, to limit the extent of failures. However, the Delta is not a science experiment. Performing some field experiments may sometimes be desirable to provide timely information to help improve management, but such experiments cannot provide absolute certainty and should not be used as a strategy to delay decisions. Computer modeling is another form of experimentation, based on mathematical representations of our current knowledge. In some cases, trial or modeled solutions should allow us to accelerate decisionmaking by making small experimental decisions in the field or in computerized settings. The original forms of adaptive management (Hollings, 1978) envisioned a close relationship among computer model development, field experiments, and management policies over time. However, the urgency of the Delta's problems probably will not permit casual, nonaggressive forms of adaptive management to be successful. Only more aggressive forms of adaptive management are likely to succeed in developing understanding and management approaches in time to preserve species that are now severely at risk.

Phased Implementation

The instantaneous implementation of a complete solution package is unlikely. Any solution is likely to require too much capital to be implemented all at once, and there will most likely be too many uncertainties and controversies to address in the course of implementation. For these reasons, phased implementation is likely to be both necessary and desirable. Phased implementation can take two forms: (1) planned phased implementation, in which the details in a phase are scheduled and orchestrated, and (2) opportunistic implementation, in which events in the Delta provide opportunities to make desirable changes relatively easily. An example of this second type would be failure of a levee on an island that is scheduled to become open water habitat or a floodway. Such a failure would present an opportunity to accelerate this phase of a long-term plan. To take advantage of such opportunities, it would be helpful to develop a "do not resuscitate" list of nonstrategic Delta islands, as described below. Phased implementation would also allow us to make progress and establish strategic direction, while adapting the strategy as uncertainties become better understood.

Stakeholder Involvement in Implementation and Operations

The many functions of the Delta are operationally complex. One concrete accomplishment of the CALFED process has been improved operational communication and coordination among various interests regarding Delta water management activities. Communication and coordination will be desirable features for the operation of any future Delta alternative. The many parties interested in the Delta have expertise and resources that are unavailable to the state and federal agencies that are charged with developing and implementing solutions. Local reclamation districts are probably the best experts on current levees; similarly, local developers and city officials know a great deal about urban land potential; and water contractors know the most about achieving water quality goals for their customers. This is not to say that the solutions to the Delta's problems are likely to be developed purely by consensus, given the inevitable tradeoffs involved. But local expertise should be involved to improve the design and implementation of Delta solutions. Centralized and isolated crafting of solutions to complex local problems is unlikely to be successful.

Reducing and Managing Uncertainties

Although our knowledge about some key drivers of change in the Delta has increased greatly in recent years, some major uncertainties still may affect the viability or design of different Delta alternatives. There is also considerable uncertainty as to how various alternatives would affect ecosystem performance, water supply and quality reliability, and other objectives. As part of any exercise to craft detailed long-term solutions, investigations will be needed into these areas. These investigations may include problem-oriented modeling and laboratory analysis as well as field experimentation. To be useful, investigations will need to be conducted in a coordinated manner.

- **Climate change.** To date, we have a general understanding of the effects of climate warming on the Delta. Faster melting of the Sierra Nevada snow pack is likely to increase the risk of flood events, and sea level rise is expected to raise pressures on Delta levees (see Chapter 3). Although we know that sea level rise could increase western Delta salinity under current operations (Department of Water Resources, 2006), we know relatively little about the effects on salinity under different operational scenarios. Hydrodynamic modeling studies are beginning to explore such effects. Research is also needed to help clarify how changes in water temperature will affect the distribution and abundance of some native and alien species, including delta smelt, striped bass, and overbite clam.
- **Alien species.** Given the dominance of alien species within the Delta, finding management techniques to discourage alien invaders and to encourage the few remaining native species is a major challenge. There are important gaps in our knowledge of the response of existing alien species to salinity, velocity, water clarity, and other manageable aspects of physical habitat. Short-term research efforts can help assess viable management solutions. Policy actions (discussed below) will be needed to help stem the arrival and establishment of new invasive species.

- **Runoff contamination.** Many investigations have concluded that spikes in contaminated runoff from agricultural and urban areas may be an important contributor to the decline in open-water fish species such as the delta smelt (Dileanis, Bennett, and Domagalski, 2002). Regulations are being introduced, but this process is slow and politically difficult. Knowing more about runoff and its effects will assist in environmental planning and policy implementation for both land and water uses.
- **Urbanization.** Although the general context of urbanization pressures in the Delta is well understood, there is as yet no clear understanding of the extent to which development in the Delta is compatible with environmental sustainability and no overall analysis of its implications for flood risks. Should urbanization be directed away from some areas or guided by special subdivision and building regulations in some others? How should flood control and local drainage be managed for these areas?
- **Recreation.** There is an urgent need to better understand the scale and scope of current and potential recreational uses of the Delta. The Delta is already an important recreational resource. As the region's population grows, it is quite likely that the economic benefits of recreation will overshadow those of traditional agriculture, if it does not already do so.[5]
- **Failure recovery costs.** Many of the Delta alternatives have a significant probability and cost of failure, from levee failure or other causes. These costs and probabilities should be assessed to serve as contributions to the development and comparison of alternatives. The current DRMS effort is providing useful work in this regard for island levee failures under current conditions (www.drms.water.ca.gov; Jack R. Benjamin and Associates, 2005).
- **Ecosystem research.** As discussed in Chapter 4, a variety of directed research is needed to more precisely and accurately define the habitat needs of key species and inform the acquisition and management of many particular habitats and locations.

[5]The long-term potential of recreation was highlighted at a workshop on Delta land use organized by a group of landscape architects from UC Berkeley and the Natural Heritage Institute in March 2006.

- **In-Delta land use and habitat.** Although our analysis suggests that the local specialization of island uses and the allowance of fluctuating salinity within the Delta offer many advantages, there is as yet limited knowledge of the best environmental and economic uses for individual islands and other peripheral areas. Such information is essential to assess the costs and benefits of managing the Delta through local specialization. Habitat plans that incorporate contingencies and uncertainty will better allow us to learn, adapt, and take advantage of opportunities.

All major uncertainties cannot be resolved before decisions on the Delta should be made. But not all issues are critical to all decisions. A successful long-term strategy should have a consistent general approach. Some components can be undertaken quickly or in stages with little uncertainty, whereas others can be delayed until there is greater clarity (but probably not perfect certainty). And some components will need to be experimental in nature.

The greatest error would be to wait and make decisions only when all uncertainties have been eliminated. There is cost and considerable risk from inaction and indecision, and action must be taken before dire events unfold. Many important decisions and directions can and must be established with existing scientific and technical understanding of the Delta and its uses. Uncertainty can rarely be eliminated; it must always be managed.

Crafting, Evaluating, and Gathering Support for Better Alternatives

Though preliminary, the evaluations presented here provide some insight into what kind of alternatives for managing the Delta would be desirable or undesirable overall. Moreover, the approach we have taken—to explicitly evaluate stated alternatives on a range of performance objectives—is a rational and promising way to arrive at an alternative that will function well on the ground. But our analysis is neglectful in three ways. Technically, our effort was too limited in time and resources to consider detailed operational plans or to conduct in-depth evaluations. Second, given the limited scope of this work, we were unable to examine a wider range of hybrid alternatives. Nevertheless, we believe that our analysis provides a good coarse filter for winnowing out unpromising approaches and for introducing promising ideas into ongoing discussions. Third, politically, our analysis is purposefully naïve. No good technical solution is likely to be implemented without political support. But the converse is also true. On its own, a political process will not be able to develop new technical alternatives or provide a technically sound analysis of alternatives. A careful and disinterested technical process—at arm's length from the political process—will be essential for crafting a viable future for the Delta.

Basing Solutions on Improved and Integrated Understanding

Developing and evaluating solutions for the Delta's complex problems will require a technical synthesis of existing and new information across a wide range of Delta-related subjects and perspectives. Such synthesis is most transparent, rigorous, and effective if conducted with the explicit aid of computer models (California Water and Environment Modeling Forum, 2005). To make results more reliable and insightful, quality control and visualization tools are important aspects of this synthesis. Despite significant investments in scientific and technical tools, the scientific and policy communities have neglected the development and testing of models and data that integrate the many aspects of ecosystem functioning, water supply and quality, and land use that determine the viability of various Delta services. The CALVIN and DAP models applied in Chapter 6 are primitive examples of what can and should be accomplished in this regard. Many models for hydrodynamics and water quality (DSM2, FDM, etc.), operations planning (CALSIM), and economics (CALAG and LCPSIM) also exist and should have important roles. To date, none of these models are entirely suited to the types of studies needed to map out long-term futures for the Delta. Models of land use and habitat in the Delta (perhaps expanding on DAP) would provide a basis for integrating land, water, and habitat decisions for the Delta. It is necessary to prepare a technical basis for exploring, developing, and comparing detailed Delta alternatives.

A combination of basic and applied research also will be required to address or narrow some of the major uncertainties noted above. Most of this research should be developed within a solution-oriented framework, as opposed to using an exploratory, basic science approach. Although our understanding of the Delta's complex problem will never be perfect, the scientific and policy communities have not made the most of integrating what we do know and have not always focused research efforts strategically on the most important questions. By developing and documenting an integrated understanding of the Delta, we will have an unprecedented ability to develop and test potential solutions and provide greater scientific assurance that taxpayer and stakeholder resources are being effectively employed.

Short-Term Actions

Solving the Delta's problems cannot occur quickly, even if action begins immediately. Developing and implementing a deliberative and thoughtful solution to this long-term problem will require years rather than months. In the face of this long-term strategic decision for California, prudence suggests several short-term actions:

- **Establish emergency-response and preparedness plans.** Levee failures are likely to occur at any time, as illustrated by the failure of the Lower Jones Tract levee in June 2004. Federal, state, and local agencies need to be prepared for large and small failures on short notice. The state and many local agencies have realized this problem and are taking useful steps. For water agencies that rely on Delta water, necessary measures include developing extended water export outage plans. With measures such as regional interties, water sharing agreements, local supply development, and drought contingency plans, the costs of losing a year of Delta exports can be reduced by a factor of 10 (Chapter 6). Other infrastructure providers that rely on the Delta, such as Caltrans, the railroads, and power companies, need similar contingency plans and should consider making new investments so that their networks are less susceptible to levee failure (for instance, burying pipelines or repositioning stretches of road). Creating a program for the rapid repair of critical levees—such as the one launched in 2006—and emergency flood response plans are also urgent.
- **Create a "do not resuscitate" list of Delta islands.** To safeguard the state's financial resources and force some movement toward a

long-term solution, the state should create a "do not resuscitate" list of Delta islands that do not have strategic value in terms of homes, infrastructure, or water supply. When these islands fail, the state would not intervene. It is already apparent that preserving or rebuilding levees for some islands is not in the state's interest (Logan, 1990). This is an important policy decision that would provide important financial savings. As noted above, it would also facilitate experimentation with environmental uses of flooded islands for habitat and flood bypasses.

- **Provide protection for urbanizing areas.** One of the few drivers of change in the Delta that we can affect is urbanization. Once established, however, urbanization of land is essentially irreversible. There is a need to protect existing urban development, but urbanization should not occur in locations that cannot or will not be protected from flooding. Local land use controls have not always been sufficient in this regard. New development projects should not impose irresponsible levels of risk on local residents and state and local governments. Habitat of particular value to Delta species should be acquired through purchases or set-asides (see Chapter 9).
- **Prevent the introduction of new invasive species**. In addition to existing problems with alien species, the Delta faces the continual threat of the arrival of new species, which can upset whatever balance has been achieved with previous invaders. Risk reduction can be accomplished through better regulation of known sources of alien species (e.g., ballast water and the aquarium trade) and better preparation to eradicate new invaders before they spread (e.g., northern pike). There is also a need for emergency response and preparedness for new invasions; rapid eradication of an invader while it is still localized can prevent future problems.
- **Initiate a technical solution effort.** A coherent and substantial effort currently does not exist for identifying, exploring, developing, and evaluating promising long-term technical solutions for the Delta. This effort will require development of data, modeling, and visualization tools to form the foundation of technical studies and to provide assurances and the communication of results for policymaking. A solution-oriented science program also is needed.

This technical effort will be a necessary part of any process to find and implement an effective long-term solution for the Delta.

- **Focus on Suisun Marsh and Cache Slough.** These two large areas have favorable prospects, from an ecosystem perspective, under various Delta change scenarios. Studies should begin immediately to model the likely future effects of the major drivers of change in these areas and to suggest how these effects can be managed to favor desirable organisms and hydrologic pathways. Land acquisition or easements should begin immediately, from willing sellers, in areas that are most likely to be affected by flooding and levee failure or to be beneficial to desired species. Planning and management efforts that are already under way in both areas should be enhanced to improve landowner and stakeholder understanding of alternative futures. Similar efforts should be undertaken in other areas peripheral to the central Delta, such as the Cosumnes River area, that are or have the potential to become centers of abundance for desirable species.
- **Begin discussions of governance and finance.** Technical studies are likely to require several years to complete. Discussions and agreement on the governance and finance of any Delta solution will likely take at least as long and involve at least as many difficulties. Such discussions should begin soon. Technical, political, and financial work all need to occur simultaneously, although not always in the same room. Having some distance between the political and technical processes provides state and federal elected officials with greater assurance that final proposals have received both stakeholder and technical scrutiny and evaluation. In the next chapter, we provide some thoughts on how to move forward in developing financial and governance options for the Delta.

On its own, a stakeholder- or policy-driven process is unlikely to generate functional long-term solutions to the Delta's problems. For this reason, a serious, systematic technical effort, which has been largely absent in the recent past, will need to accompany exercises such as the Delta Vision effort. Such a technical effort can and should enrich policy discussions by suggesting promising new alternatives, deterring unproductive discussion of unpromising alternatives, and providing voters and elected officials with greater confidence and information on the costs, benefits, and likely tradeoffs of alternative solutions.