PUBLIC POLICY INSTITUTE OF CALIFORNIA

Where the Wild Things Aren't

Making the Delta a Better Place for Native Species

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Summary

Management of the Sacramento–San Joaquin Delta is one of California's greatest challenges, because the lands and water resources of the system serve a multiplicity of conflicting purposes. The native wetlands of the estuary have been dredged and diked to support farming, transportation, commerce, and housing development. Diversions from the Delta watershed now provide water for much of California's population and economy. The development of the Delta's lands, the channelization of its waterways, the discharge of pollutants, the introduction of non-native species, the alteration of flows, and the diversions of water from the system have combined to degrade the quality of water and habitat. These stressors, singly and in combination, have harmed native species that inhabit or pass through the estuary. In addition, accelerating sea-level rise, warming temperatures, increased frequency of extreme flood events, longer droughts, and other manifestations of climate change will be changing the environment, making management even more difficult.

This report proposes a reconciliation approach for addressing 160 years of accumulated problems and for managing the Delta's ecosystem in the future. Reconciliation ecology seeks to improve conditions for native species while recognizing that most ecosystems have been altered irrevocably by human use and will continue to be used to support human goals. Improving ecosystem conditions for native species must therefore happen in a context of continuing use of land and water by humans and continuing physical and biological change.

The "Reconciled Delta" described in this report represents our collective judgment on how to approach the management of the Delta's water and land resources in a manner that might *realistically* achieve the California legislature's co-equal goals of water supply reliability and ecosystem protection for the Delta as an evolving place (Delta Reform Act of 2009, Water Code § 85054). We focus on the most technically vexing aspect of this problem: defining and maintaining essential ecosystem functions so that populations of endangered or threatened aquatic species will recover to sustainable levels and other native species will continue to thrive. The decline of native fish species that depend on the Delta ecosystem has been a central management challenge for this region for several decades, with numerous adverse ramifications for human users of water and land resources. Improving environmental outcomes is necessary to sustain the local Delta economy and to support more reliable water supplies for regions beyond the Delta.

Our conclusions were informed by a broad investigation of scientific literature and a series of energetic and stimulating discussions with experts on the hydrology, biology, and ecology of the Delta. We take as given several points for which there is considerable scientific support:

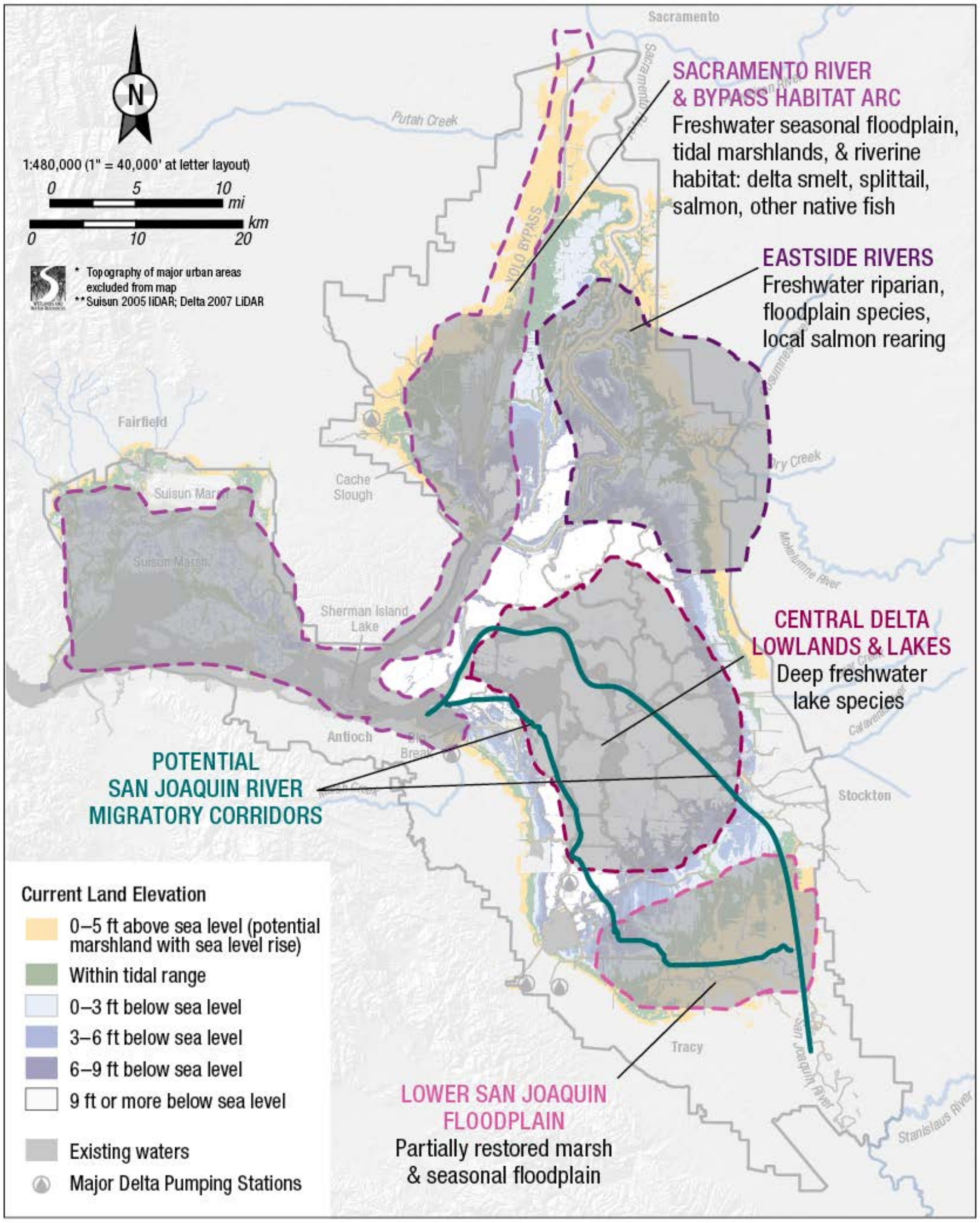
1. **The Delta ecosystem will continue to experience major changes.** Land subsidence, sea-level rise, earthquakes, floods, climate change, new invasive species, land development, and the inability of landowners and governments to protect Delta islands from flooding will all shape the future Delta.
2. **Numerous constraints limit environmental management options.** The most restrictive constraints are physical and biological, including widespread land subsidence, limits on the availability of fresh water, and the domination of the ecosystem by invasive species. Economic, financial, legal, and institutional constraints also restrict human ability to manage the Delta ecosystem.
3. **Society has some capacity to improve Delta ecosystem conditions and support sustainable populations of the native species that inhabit or pass through the Delta.** However, restoration of abundant populations of *all* native species is unlikely, and some may become extinct in the wild even with extraordinary efforts to sustain them.

4. **Managers will need to address multiple sources of stress to the ecosystem within and upstream of the Delta.** These include altered flows and sediment, degraded physical habitat, contaminants and nutrients, invasive species, and hatchery policies.
5. **The physical environment can be managed to aid populations of native aquatic species (as well as some desirable alien species).** To achieve this, physical habitats and flows can be managed, where possible, to provide conditions that native estuarine species need at different stages in their lives.

These conditions and projected trends lead to the following conclusions regarding a reconciled aquatic ecosystem in the Delta:

1. **Natural processes place limits on all water and land management goals.** For instance, roughly 95 percent of the Delta's tidal marshland—the primary pre-development habitat in which native species thrived—is now gone. But most of the central and western Delta is too deeply subsided to be restored to marshland, and the permanent flooding of islands in this region may diminish the tidal energy needed for tidal marshland development elsewhere. Tidal marshes can be recovered over time in much of Suisun Marsh and the periphery of the western and northern Delta. Restored lowlands adjacent to rivers in upstream areas can provide seasonal riparian and floodplain habitat for native species.
2. **Specializing different parts of the Delta for different functions is the most promising way to accommodate native species and support other desired uses of the Delta.** Although much of the historical diversity in Delta habitat has been lost, important regional differences persist. A reconciliation strategy should capitalize on these differences (Figure S1):
   - An arc of connected habitats extending from Suisun Marsh and Big Break to parts of the northwestern Delta and the Yolo Bypass is most suitable for the Delta's native estuarine species (e.g., delta smelt, salmon, and splittail). This region would consist of both brackish and freshwater tidal marshland and shallow subtidal habitat as well as open water channel habitat.
   - Given the likely reduction in tidal energy with island flooding, habitat re-creation in the southern Delta would be primarily non-tidal, with seasonal floodplains, flood bypasses, and marshes fed by the San Joaquin River. This habitat could support migratory birds and the rearing of migratory fish, including Chinook salmon.
   - Riparian and seasonal floodplain habitat would be developed in the eastern and northern Delta, supporting spawning and rearing of migratory species.
   - Some deeply subsided islands in the central Delta are destined to become flooded deep-water "lakes," which will likely benefit primarily non-native recreational fish species (e.g., largemouth bass). Migratory fishes and ships will continue to need passage through this region. Islands with high economic and strategic value would continue to be protected.

FIGURE S1
Habitat area specialization is a key to shaping a reconciled Delta



SOURCE: Base elevation map adapted from Stuart Siegel, Wetlands and Water Resources, Inc., 2009.

NOTE: This map shows ecosystem areas as regions. As described in the text, these regions would continue to support most urban and agricultural land uses as well as transportation functions. Islands within the central Delta whose economic value (including for strategic uses like roads and rail lines) justifies the expense would continue to be protected.

3. **Levees, channels, and flow alteration are essential tools for managing the Delta's physical structure.** These tools were initially used to facilitate the farming and habitation of Delta lands, and later to enhance flood control and navigation. Since the 1950s they have also been used to facilitate the transport of water from the Sacramento River to Central Valley Project and State Water Project pumps in the south Delta. In a reconciled Delta, these tools would be used to work more *with* nature to benefit native estuarine species, as well as to provide long-term benefits to humans. A more native fish–friendly flow regime and an appropriately modified system of levees, channels, barriers, diversions, and islands should help shape and support a reconciled Delta by

- Allowing for natural processes to develop various forms of habitat (e.g. tidal marshes and seasonal floodplains).
- Supporting migration of salmon and other native fish species by creating rearing habitat for juveniles and by directing them away from lethal areas in the central Delta and near the south Delta pumps.
- Protecting existing development, infrastructure, and high-value agriculture.

4. **It may take decades before the Delta can once again support sustainable populations of most native species**. In the interim, sustaining some native species may require unconventional measures, such as hatcheries managed for genetic diversity.
5. **The Delta needs an effective, adequately funded system of adaptive management.** This system would integrate modeling, experimentation, and feedback into management decisions. Over-negotiation of details in advance is unlikely to enable adequate responsiveness and flexibility. However, we must recognize that even the most well-informed, scientifically based management will encounter surprises and make mistakes. Such surprises and mistakes are increasingly likely as climate change adds an additional element of unpredictability to management.

This vision of a reconciled Delta is compatible with key federal and state environmental laws governing the Delta. It also proposes a path to create a Delta in which humans and native species successfully co-exist and respond positively to change. Although this framework seeks to accommodate sustainable human and environmental uses of water and land in the Delta, some additional societal sacrifices will be required to support the environment, whose needs have been underserved since humans first began significantly altering the lands and waters of the Delta ecosystem in the 1850s. Mitigation may be appropriate to help groups that experience direct and significant changes to their livelihoods as a result of these changes, such as those who live and work on lands that are appropriate for habitat development or that will be subject to permanent flooding. Ecological reconciliation may be expensive, but it is likely to be less costly and more environmentally effective over the long term than a series of reactive responses to continuing crises in the Delta. Ecological investments in the Delta will ultimately benefit California's economy by securing higher-quality, more reliable water for agriculture and urban use, averting expensive responses to natural disasters, and expanding recreational opportunities. Ecosystem and economic objectives are mutually dependent. Laying out a strategic direction that recognizes this interdependence is necessary to guide effective plans and policies.

Companion reports

This report presents results from two surveys conducted in summer 2012 regarding ecosystem management in the Sacramento-San Joaquin Delta. It is part of a wide-ranging study on the management of multiple ecosystem stressors in the Delta. For a summary of overall study findings, see *Stress Relief: Prescriptions for a Healthier Delta Ecosystem* (Hanak et al. 2013). Several companion papers address related topics in greater depth: (1) *Aquatic Ecosystem Stressors in the Sacramento-San Joaquin Delta* (Mount et al. 2012) summarizes the science of Delta ecosystem stressors for a policymaking audience; (2) *Costs of Ecosystem Management Actions for the Sacramento-San Joaquin Delta* (Medellín-Azuara et. al. 2013) provides cost estimates for a suite of management actions addressing various sources of ecosystem stress; (3) *Integrated Management of Delta Stressors: Institutional and Legal Options* (Gray et al. 2013) presents our proposals for institutional reform of science, management, and regulation; (4) *Scientist and Stakeholder Views on the Delta Ecosystem* (Hanak et al. 2013b) presents the results of surveys of scientific experts and engaged stakeholders and policymakers on Delta stressors and management actions. All of these reports are available on PPIC's website at www.ppic.org.

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Abbreviations

AM	Adaptive Management
AMA	Adaptive Management Alliance
BDCP	Bay Delta Conservation Plan
CVP	Central Valley Project
CWA	Clean Water Act
DSP	Delta Science Program
ESA	Endangered Species Act
HCP	Habitat Conservation Plan
NCCP	Natural Community Conservation Plan
SAFCA	Sacramento Area Flood Control Agency
SWP	State Water Project

Introduction

It is change, continuing change, inevitable change, that is the dominant factor in society today. No sensible decision can be made any longer without taking into account not only the world as it is, but the world as it will be.

—Isaac Asimov

The most vexing problem in California water policy is the Sacramento–San Joaquin Delta, a network of mostly man-made islands and channels at the confluence of the Sacramento and San Joaquin Rivers. Together with San Francisco Bay, the Delta forms the largest estuary on the Pacific coast of the Americas. It is the terminus of California's largest watershed and a major source of the state's water supply. It is also a valued ecological resource.

For decades, Californians have struggled to use the Delta to provide a reliable water supply for cities, farms, and businesses, and for other beneficial uses, while also protecting the system's environmental values. In this report, we describe a direction for water managers and policymakers to create a balanced, functioning, and sustainable Delta that will enable Californians to serve as good stewards of this valuable natural environment and escape the paralysis engendered by seemingly intractable legal and political conflicts.

Pursuing the "Reconciled Delta" proposed here is only one of a variety of alternative policy trajectories for this region. At one end of the ecological and policy spectrum is the option of attempting to restore the Delta to resemble the tidal marsh that it once was before hydraulic mining, levee construction, upstream and in-Delta agricultural development, dam construction, and operation of the great water projects wrought profound changes on the system. At the other end of the spectrum is the repeal or amendment of environmental laws such as the Clean Water Act (CWA) and the Endangered Species Act (ESA) as they apply to the Delta ecosystem to support largely unfettered management of the region for agricultural and urban water supply and land use. A middle alternative is to continue long-standing legal and administrative processes that manage the Delta by crisis, with the CWA and ESA continuing to provide minimum environmental baselines that require reductions in water deliveries in response to droughts and regulatory mandates.

None of these alternatives is practical or desirable. The structural changes to the Delta landscape have been so vast that a return to a hypothetical "natural" Delta has little chance of ecological success. It would also largely exclude the people who live, farm, and recreate in the Delta as well as the millions of people and businesses throughout California who depend on the impoundment, diversion, and export of water from the system.

The opposite alternative of a Delta fully dedicated to agricultural and urban water supply and land use is equally unrealistic and indefensible. Casting major environmental regulations aside may improve the Delta system's ability to meet human demands for water supply and land, but there would be costly consequences for the quality of water deliveries, fisheries, recreation, and other benefits provided by a well-functioning ecosystem. Such "ecosystem services" provide a range of economic and cultural benefits to Californians. An unregulated Delta would neither fulfill society's responsibilities to act as responsible stewards nor serve the interests of most Californians, who value both economic prosperity *and* environmental amenities.

Maintaining the status quo is not acceptable either. If water managers and policymakers have learned nothing else from the decades-long quest to accommodate the many economic and environmental interests in the waters of the Sacramento–San Joaquin River and Delta system, it is that water supply reliability depends on a functional and sustainable ecosystem. Californians—and the native fishes that depend on the

Delta ecosystem—do not have the luxury of indefinitely prolonged decisionmaking as the system lurches between water shortages and endangered species crises, which will only get worse under projected climate change effects. Ecosystem objectives and economic uses of the Delta are mutually dependent.

The Reconciled Delta proposal described in the following pages is the result of a series of energetic workshop discussions with experts on the Delta's biology, hydrology, and ecology conducted during the summer and fall of 2011. It represents our current judgment on how to approach the management of the Delta's water and land resources in a manner that might *realistically* achieve the California legislature's co-equal goals of water supply reliability and ecosystem protection for the Delta as an evolving place (Delta Reform Act of 2009, Water Code § 85054). We provide a general direction, not a detailed roadmap for change. And while our approach is grounded in the broader goal of balancing environmental and human demands on Delta resources, our focus here is on the aquatic ecosystem. How can society support sufficient ecosystem functions so that most endangered and threatened aquatic species recover to sustainable population levels, other native species thrive, and the aquatic habitat on which these species depend is improved and protected? This is both the central source of conflict and the most difficult technical challenge for reconciliation.[1]

A Trajectory of Widespread Deterioration

Today, the Delta continues to deteriorate in many ways (Mount and Twiss 2005; Healey, Dettinger, and Norgaard 2008; Lund et al. 2007, 2010; National Research Council, 2012). Almost all stakeholders and interests are witnessing declines in the conditions they favor, and further deterioration is likely. Sea-level rise and continued land subsidence on many islands require increased pumping to drain subsided islands, and more costly levee repairs and improvements. Given these costs, permanent flooding of some deeply subsided islands in the western and central Delta is likely (Suddeth, Mount, and Lund 2010). Urban and agricultural water exports from the south Delta pumps are becoming less reliable as endangered species concerns disrupt pumping schedules. Earthquakes have the potential to cause widespread flooding of subsided islands and a surge of salt water into the Delta (URS Corporation and Jack R. Benjamin & Associates 2009). Transportation, energy, water, and communication corridors across the Delta are at growing risk of flooding from levee collapse.

Water quality concerns also loom large. It is becoming more expensive to meet drinking water standards with Delta waters, which are high in organic matter and bromides (Chen et al. 2010; Malcolm Pirnie, Inc. 2011). Salts contained in water diverted from the Delta to the San Joaquin Valley threaten long-term agricultural production (Medellín-Azuara et al. 2008). In turn, drainage from some lands irrigated with Delta water returns to the San Joaquin River and the southern Delta, adding salts, heavy metals, pesticides, and other pollutants along the way (Giddings, Hall, and Solomon 2000; Werner et al. 2010). The growing urban areas around the Delta's core also add pollutants to Delta waters. Wastewater treatment plants, urban stormwater run-off, and agricultural discharges contribute toxic pesticides and high nutrient loads to the Delta (Weston and Lydy 2011; Nichols et al. 1986; Hager and Schemel 1992; San Francisco Bay Water Quality Control Board 1995; Kratzer and Shelton 1998, Kratzer et al. 2004; Lehman et al. 2004; Jassby and Van

[1] This report is part of a larger study on the management of multiple stressors in the Delta, which is looking at a range of technical, legal, institutional, and economic issues related to the improving environmental outcomes in this complex and troubled region. A companion report, *Aquatic Ecosystem Stressors in the Sacramento–San Joaquin Delta* (Mount et al. 2012) provides an overview of the multiple sources of stress affecting the Delta's native fish species and summarizes potential remedies. Future publications will seek to prioritize stressors and mitigation actions and provide options for funding these actions and managing stressors in a more integrated and effective manner.

Nieuwenhuyse 2005; Dugdale et al. 2006; Glibert 2010). Moreover, abandoned mines and other land developments continue to add "legacy contaminants" to the system. Mercury remobilized from Gold Rush era sediments is a special source of concern to human health, as it concentrates in the tissue of edible fish (Shilling et al. 2010).

Last, but not least, native fish species and their habitats continue to deteriorate under the accumulating weight of many stressors, almost all of which are caused by past and present human actions (Table 1, National Research Council 2012). Populations of several species listed under state and federal ESAs reached record low numbers in recent years, and additional listings are likely (Sommer et al. 2007, Moyle and Bennett 2008, Moyle, Katz, and Quiñones 2011). These declines have persisted despite decades of well-intentioned efforts to improve conditions for native species in the Delta and are likely to continue overall despite the positive effects of favorable environmental conditions in some years (e.g., 1995–2000, 2011).

Reconciliation Ecology: A Novel Approach for a Novel Ecosystem

One and a half centuries of intensive land and water management within the greater Delta watershed have transformed the Delta's ecosystem from a largely natural landscape to a largely domesticated environment—a "human habitat" in which other species also live.[2] In such a "novel ecosystem" (Hobbs, Higgs, and Harris 2009), traditional approaches to environmental management - including conservation, preservation, and restoration—are unlikely to significantly improve conditions for native species. Although such strategies may still work in parts of the Delta, they will not be adequate to manage the Delta as a whole. For example, dedicated nature reserves often greatly restrict human uses and, in principle, attempt to exclude alien species. Yet pervasive human alterations of the Delta make such traditional approaches both politically unviable and physically and biologically infeasible (Hanak et al. 2011; Moyle 2011; Mount and Twiss 2005).

In contrast, reconciliation ecology focuses on sustaining biodiversity and ecological services in ecosystems that have been substantially altered by human actions and in which humans continue to maintain an important presence (Rosenzweig 2003, Dudgeon et al. 2006, Geisler 2010, Lundholm and Richardson 2010). Instead of just setting aside habitat for the benefit of one or more non-human species, a reconciliation approach tries to find ways for humans and other species to share habitats, although this may require intensive management of some areas for particular species. It assumes that alien species and highly altered landscapes can be part of sustainable ecosystems, but the ecosystems may be novel in many ways. It also assumes that most native species will have large enough populations to be able to adapt to environmental change, in part through evolutionary mechanisms.

The management toolbox for reconciliation ecology combines traditional preservation and restoration strategies with civil and ecological engineering and adaptive management. Reconciliation also requires an open, comprehensive assessment of each ecological system, with clear goals for management and open dialogue among stakeholders. Generally, conservation of most remaining native species will be a primary goal, along with maintaining ecosystem processes similar to past patterns. For example, Putah Creek

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[2] From the reports of early explorers, it has been estimated that the native human population in the Delta area was between 3,000 and 15,000, with most native villages located on natural levees on the Delta's eastern edges. The native population did not practice agriculture, although the inhabitants did manage the landscape with fire and other tools to favor plants they used (Anderson 2005). There was very limited settlement by non-native residents before the end of the 1840s (Thompson 1957).

(a regulated tributary to the Delta via the Yolo Bypass) has a flow regime patterned after natural flows, but with much less water. It now supports a diverse group of native fishes even though the stream is a leveed ribbon of restored habitat within an agricultural landscape (Kiernan, Moyle, and Crain 2012).

TABLE 1
The many stressors of the native Delta aquatic ecosystem

Discharges
– Agricultural runoff (farmers: salts, selenium, pesticides, herbicides, nutrients, total organic carbon)
– Legacy mining wastes (19th century miners: debris and mercury)
– Urban runoff (cities and counties: nutrients, pesticides, herbicides, other chemicals)
– Urban wastewater treatment plant discharges (cities and wastewater districts: nutrients, salts, total organic carbon, pesticides, pharmaceuticals, endocrine disruptors, etc.)
Fisheries management actions
– Harvest (commercial fishermen, anglers, and poachers)
– Hatcheries (US Fish and Wildlife Service, California Department of Fish and Game)
– Introduction of non-native species (fish agencies, anglers—official introductions ended in 1969; ballast water)
Flow regime and quality
– Reduced Delta outflow volume (upstream diverters and groundwater pumping: 42% of average natural flow; in-Delta diverters: 3%; export pumps: 20%)
– Changed seasonal pattern of Delta outflows (upstream storage and all diverters)
– Changed flow patterns within the Delta
From pumping, gates, and barriers (in-Delta diverters and export pumps)
From ship channel dredging (Ports of Sacramento and Stockton)
From diking and draining marshlands (original Delta landowners)
– Reduced San Joaquin River inflows (upstream local and federal diverters, groundwater pumping)
– Changed Sacramento River inflows (upstream diverters and storage, groundwater pumps, and CVP and SWP export operations)
– Reduced and disruptive eastside stream inflows (Cosumnes, Mokelumne rivers) (upstream diverters and groundwater pumping)
– Anticipated effects of climate change: lower flows from longer or more frequent droughts; more frequent extreme high-flow events; lower late-summer flows from reduced snowpack; earlier peak inflows from more rain, less snow; warmer water temperatures (+ 2-6°C by 2100)
Invasive species
– Management conflicts from existing invasive species that support fisheries and/or form part of food webs
– New introduced species (from anglers, aquarium owners, shipping industry, etc.) that alter the ecosystem to the detriment of native species and human use.
Ocean conditions
– Climate change effects on upwelling, El Niño-Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), etc. (not locally manageable)
Physical habitat loss and alterations
– Reduced access to spawning upstream of dams (dam owners and operators, to support water supply, flood control, hydropower, and recreation)
– Levees and channelization, reducing riparian habitat, seasonal wetlands and floodplains (land developers and residents; floodplain drainage and reclamation; flood management operations)
– Diking and draining of 440,000 acres of tidal marshland and natural habitats along channels (original Delta landowners, 1860s–1930s)
– Reduced sediment availability (dams, farming, flood control)

NOTE: Stressor groups are listed in alphabetical order. For a more detailed discussion of stressors, see *Aquatic Ecosystem Stressors in the Sacramento–San Joaquin Delta* (Mount et al. 2012).

Reconciliation ecology thus provides a framework for managing the multiple stressors that have caused the deterioration of the Delta ecosystem (Table 1). Orienting the management of multiple stressors toward achieving a desirable future is a more practical and promising approach to environmental management than trying to undo these sources of stress to restore a simple vision of the past.

Here, we offer one view of a reconciled Delta, recognizing that many variants are possible. We focus on reconciliation for the aquatic ecosystem. There are many other facets of reconciled ecosystem management of the Delta, such as maintaining habitat for migratory waterfowl or creating habitat for endangered terrestrial species (e.g., giant garter snake), but it seems wisest to begin with aquatic conservation because this is an integral feature of all problems that plague the Delta ecosystem. It is also the most complex and challenging management problem, given the multiple interacting sources of stress on the system and the limited ability of native fishes to avoid unfavorable conditions. (Migratory waterfowl can fly to new locations with suitable habitat; avoiding inhospitable areas is harder for fish). Although this framework seeks to accommodate sustainable human and environmental uses of water and land in the Delta, we recognize that some additional societal sacrifices will be needed to support the environment. These changes are necessary because environmental needs have been underserved since humans first began significantly altering the lands and waters of the Delta ecosystem in the 1850s.

Many of the ideas advanced here will be familiar to those immersed in Delta science and policy discussions. For instance, the Delta Reform Act of 2009 calls on the Delta Stewardship Council, a new governing body for the Delta, to craft a long-term Delta Plan that restores “diverse and biologically appropriate habitats” and “functional corridors for migratory species”—two central themes for the reconciliation strategy proposed here. The Bay Delta Conservation Plan (BDCP) planning process is pursuing these same goals as it seeks to develop a long-term habitat conservation plan for the Delta under state and federal laws governing endangered species (Bay Delta Conservation Plan 2010). We consider the potential for a new export conveyance facility that draws water around or under the Delta as a way to improve management of flows for environmental purposes. The BDCP examines a variant of this strategy, “dual conveyance,” which would combine such a facility with continued through-Delta exports. We hope to inform these and other planning processes, as well as the broader community interested in the Delta, with an independent scientific perspective on a reconciled ecosystem management approach for the watershed.

Putting such a vision into place will require considerable additional analysis and a detailed ecosystem investment plan, well beyond the scope of the present report. In future work, we hope to shed further light on this planning process, with additional insights on how to prioritize among actions and more effectively address the multiple sources of stress on the Delta ecosystem.

Overview of This Report

We begin with a discussion of the management goals and objectives that underlie our approach. We then describe our vision of a reconciled Delta, which relies on regional specialization of ecosystem functions. The subsequent sections discuss key management tools and approaches to achieve this vision and some legal and policy implications of the approach, including how to devise strategies to mitigate the negative effects on some human users of the Delta system who would be unduly harmed by changes outlined here. We conclude with some summary observations.

Ecosystem Management Goals, Objectives, and Principles

The Delta has served many changing human and environmental purposes since settlers began developing the region just before California became a state. Nineteenth-century hydraulic mining discharged massive quantities of sediment into the rivers of the Sierra Nevada and into the Delta, altering hydrodynamics, increasing flooding, and causing Delta landowners to raise the height of their levees. Agriculture within and upstream of the Delta eliminated most wetlands, channelized streams, reduced flows, and increased salinity within the Delta and the lower San Joaquin River that flows into it from the south. Because agriculture on diked wetlands has caused considerable land subsidence, much Delta land is now well below surrounding water levels. Construction within the greater watershed of large flood-control and water-supply projects in the early to mid 20th century further altered hydrology and aquatic habitat, both within the Delta and upstream (Hanak et al. 2011). These changes created new habitats that favored deliberately introduced game and forage fishes, and interactions of these aliens with native fishes further contributed to the decline of the natives. This historical cascade of management objectives, actions, and responses has shifted the Delta's ecosystem irreversibly, precluding restoration of the Delta to its prior state (Moyle and Bennett 2008; Moyle, Bennett, et al. 2010). Furthermore, the Delta is continuing to change, and the pressures wrought by accelerating sea-level rise and other manifestations of climate change are likely to create a whole new set of novel conditions, especially if there is no measured management response to them. To manage the Delta of the future effectively, it is necessary to identify a relevant set of ecosystem goals and management objectives.

Goals of a Reconciled Delta

A basic set of goals for a reconciled Delta should include the following:

1. Providing sufficient habitat (including flows) to support self-sustaining populations of remaining native species, with an initial focus on fishes.
2. Providing fisheries for an array of species, with highest priority to native species (see textbox on p. 18).
3. Creating mechanisms for the ecosystem to adjust to changes in physical conditions caused by sea-level rise and climate change, to support native species.
4. Delivering reliable sources of high-quality water for human use.
5. Accommodating a wide variety of human uses within the Delta, including agriculture, flood protection, and diverse recreation.
6. Suppressing introductions of additional alien species, while reducing the effects of existing and new invasive species.
7. Accommodating the effects of climate change.

It is important to recognize that natural processes place limits on all water and land management goals. Land elevations, sea-level rise, and ecosystem changes caused by invasive species are all largely irreversible; these and other physical and biological constraints limit the room for maneuver for managing the Delta for various purposes (Table 2). For instance, it is physically and economically impractical to reestablish tidal marshland—the primary aquatic habitat in the pre-development Delta—in the deeply subsided area within the Delta's core (Figure 1).[3] Similarly, management efforts can at best hope to diminish the influence of invasive species in some areas, not to eradicate them. Socio-economic factors also impose constraints. For example, budget shortfalls are likely to restrict state and federal investments in the Delta.

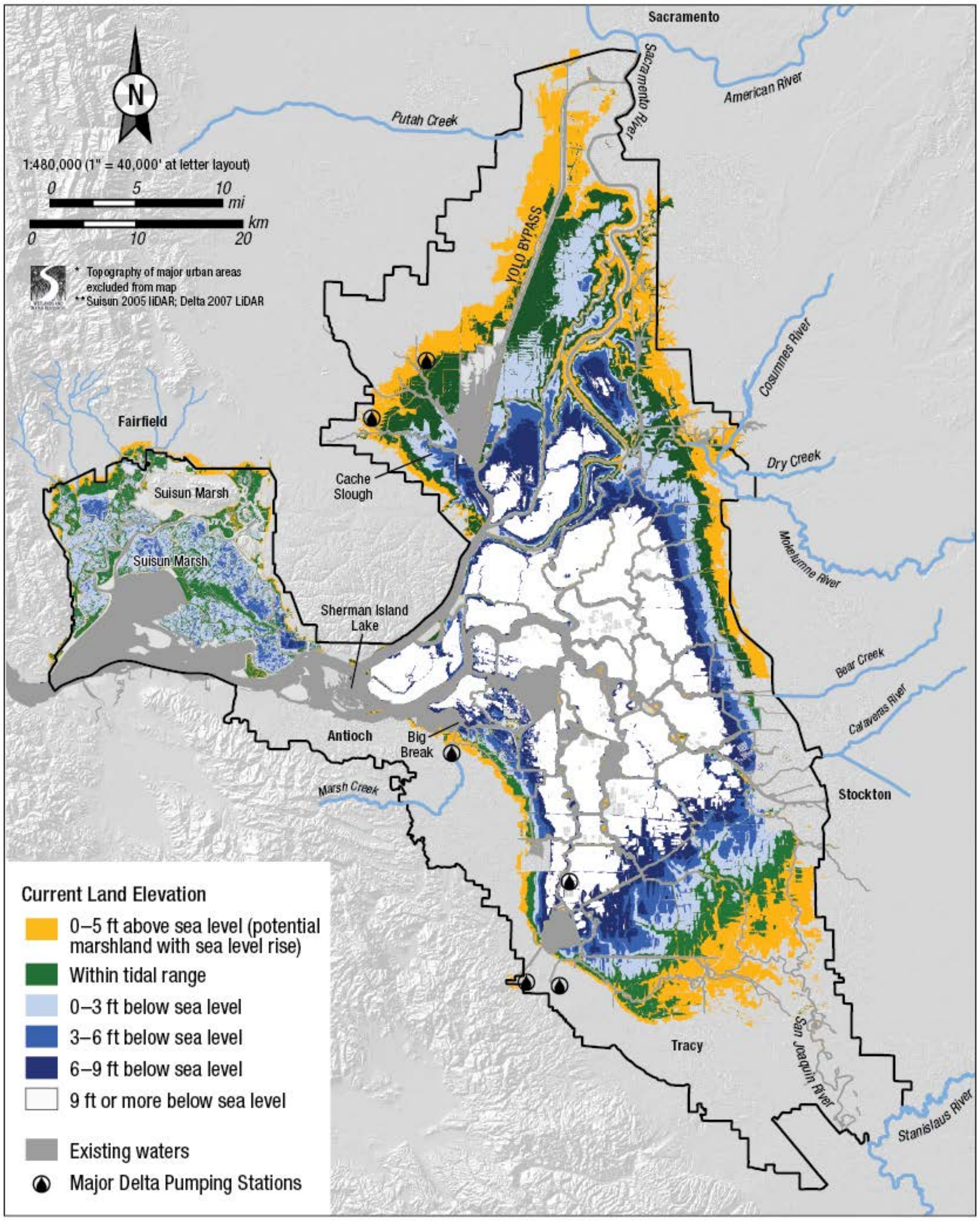
TABLE 2
Environmental constraints on a reconciled aquatic ecosystem in the Delta

Physical constraints	
Elevations	Elevations over vast areas of the Delta are far below sea level and continuing to subside, limiting the available habitat for tidal marshland restoration.
Tidal energy	Limited tidal energy from the ocean is available for tidal mixing needed for tidally influenced habitat that supports native species and their food webs.
Space	The Delta has a limited surface area to support habitats and other land uses.
Water availability	There are competing urban, agricultural, and environmental demands for limited and variable water supplies, especially in multi-year droughts.
Salt	Large inflows of salts from the San Joaquin River and the ocean alter aquatic habitats and impair urban and agricultural uses.
Temperature	Water temperatures are anticipated to rise with climate change, degrading aquatic habitat both upstream and within the Delta.
Sediment	Limited sediment inflow is available to support habitats and recover elevations.
Disinfection by-products	Increase in food web production and tidal wetland restoration can increase dissolved organic matter, posing public health risks for treated drinking water.
Biological constraints	
Alien species	Alien species will have increasingly adverse impacts on native species as climate change creates more favorable conditions for them; new invasive species will continue to arrive and alter ecosystems.
Habitat requirements	Species have specific habitat requirements that often vary with life stage. Poor-quality habitat can reduce population-carrying capacity, productivity, and fitness.
Endangered species	Small populations are subject to genetic and population bottlenecks, as well as increased vulnerability to disease, random local events, and other shocks (e.g., drought, temperature). More species are likely to be listed as long as present conditions continue.
Productivity	Productivity of the Delta (as measured by phytoplankton densities), the basis of food webs, is low compared to other estuaries, due to interacting factors including high inorganic turbidity, low residence time of water in many areas, effect of toxics, and feeding of alien clams. Changes in any of these factors could affect productivity, nutrients, food webs, and ultimately, fish.
Algae and bacteria blooms	These blooms, caused by polluted discharges from agricultural and urban sources, can release toxins and interfere with food webs under some conditions.
Contaminants	Pesticides, human hormones, heavy metals, and similar substances may adversely affect health of humans and aquatic species, and new contaminants are constantly entering the environment. Some restoration projects can increase biologically available mercury (with negative impacts for humans and other species).

NOTES: The table is illustrative.

[3] The legal Delta as a whole extends over roughly 737,000 acres, including over 90,000 acres of urbanized lands (Medellín-Azuara et al. 2012). Roughly 300,000 acres of land (40% of the Delta) now lie between 5 and 30 feet below sea level. This land is too deep for marsh plants to become reestablished, too deep for subsidence reversal efforts (such as active planting of tules) to be effective, and too large a volume to be filled with waste material from elsewhere, particularly considering the added constraint of accelerated sea-level rise. To illustrate this point, consider the effort to restore one modestly sized 5,000-acre island, with an average subsidence level of 20 feet, to current sea level. This would require 100,000 acre-feet (161 million cubic yards) of fill. Assuming it cost $10/cubic yard to acquire and place such a large amount of fill, raising this island to sea level would cost $1.6 billion.

FIGURE 1
Land subsidence restricts the availability of lands that could be restored to tidal marshland and seasonal floodplains to the Delta's periphery



SOURCE: Adapted from Stuart Siegel, Wetlands and Water Resources, Inc., 2009.

As Table 2 suggests, there will sometimes be tradeoffs between (and among) management goals that benefit humans and those that benefit other species. In addition to competing for water and land, humans and other species often have different water and land quality needs. (For instance, turbid and somewhat saline waters are important for some native fish species, but these same characteristics raise treatment costs for drinking water. Similarly, marshlands support many aquatic and riparian species, but they are unsuitable for farming or urban uses.) Groups of species can also have different, competing habitat needs—e.g., native nongame fishes versus alien game fishes versus waterfowl. Tradeoffs can also exist among the human uses, e.g., local and statewide water supply, versus recreational boating and fishing, versus flood management, versus navigation, versus agricultural or urban land use. The legislature's enactment of the Delta Reform Act of 2009—passed by bipartisan majorities in both houses—identifies the "co-equal goals" for Delta management of improving water supply reliability and ecosystem sustainability, while protecting and enhancing the "unique cultural, recreational, natural resource, and agricultural values of the Delta as an evolving place." As this language suggests, the legislature does not propose to eliminate any major goal for Delta management, but rather seeks accommodations among them. The legislature's recognition of the Delta "as an evolving place" also fits well with our strategy for a reconciled Delta.

The reconciled Delta described here focuses on achieving the most difficult goal for the Delta: improving and maintaining sufficient ecosystem functions so that endangered or threatened species will recover to sustainable population levels and other native species will not fall into jeopardy. Species extinctions cannot be reversed. Both the federal and state ESAs require that habitat be managed to accommodate the most vulnerable species. But with a reconciliation approach, native species preservation need not be the only environmental management goal or outcome. There are also clear roles for other "desirable" and even some "non-desirable" alien species (such as alien species important as food or habitat for native species or important for recreational fishing, as described in the text box), just as there are roles for continuing human uses of Delta lands and waters.

It is important to approach the goal of supporting the Delta's native species realistically. Many of these species already have severely compromised populations, making them more vulnerable to disease and other shocks such as severe drought. Some anticipated physical and biological changes, including rising temperatures and new invasive species, will cause further harm, increasing the likelihood of extinction from chance demographic or environmental events (Melbourne and Hastings 2008). Although society has some capacity to reduce undesirable changes to Delta ecosystem conditions and support populations of native species, restoration of abundant populations of *all* native species is unlikely if present trends continue.[4] Some species may become extinct in the wild even if society undertakes extraordinary efforts to sustain them (Hanak et al. 2011). By supporting ecosystem functions that favor native species, reconciliation is the most promising approach for sustaining most native species in the highly altered environment where they now live.

Management Objectives for a Reconciled Delta Ecosystem

California's climate has great seasonal and interannual variability in temperature, precipitation, and the resulting timing and magnitude of runoff (Dettinger et al. 2011). High variability in environmental conditions, combined with the complex physical landscapes that once characterized the upper San Francisco Bay Estuary, made for a highly productive aquatic ecosystem (Whipple et al. forthcoming). This seasonal and interannual variability in flows and the extent of floodplain and wetland habitat has declined as the ecosystem has been simplified and domesticated for human uses. To manage floods, water exports, and

[4] For instance, in a 2008 survey, a sample of 39 biologists and other ecosystem experts on the Delta projected that the delta smelt and longfin smelt had at best a 40 and 60 percent likelihood, respectively, of remaining viable in the wild by 2050, even if all water exports from the Delta ended (Bennett et al. 2008). The likelihood of a viable Sacramento River fall-run Chinook salmon fishery by 2050 was at best 60 percent.

Desirable species for a reconciled Delta

Reconciliation ecology requires choices of which species should be favored by management actions. These "desirable species" can be both native and alien species. However, federal and state ESAs recognize native species as core desirable species. These laws express broad societal goals to protect native species and prevent extinctions. The impact of these laws in California is especially strong because so many of the species (e.g., 60% of all native fishes) are found only in this state, with no refuge populations elsewhere. Supporting native endemic fish species in the Delta is a major challenge: they currently make up less than 20% of the region's fish biomass; six species are listed as threatened or endangered (delta smelt, longfin smelt, Central Valley steelhead, southern green sturgeon, and winter- and spring-run Chinook salmon). In addition, 25 other Delta species are listed under the ESAs (Healey, Dettinger, and Norgaard 2008). Although native sturgeon, salmon, and steelhead fisheries have high value to humans, many native species are rarely seen and little appreciated by the general public (e.g., delta smelt, longfin smelt; Suisun song sparrow, Mason's lilaeopsis).

Some alien species in the Delta also provide recreational and economic benefits that make them desirable to important segments of society. Striped bass and American shad are major sport fishes that generally require the same estuarine environment as native fish species or use habitats compatible with native species (Moyle 2002). But alien species such as largemouth bass, which also support recreational fisheries, have different habitat requirements. The most numerous and diverse alien species are aquatic invertebrates, which often serve as principal foods of native fishes and birds. Even native river otters thrive on non-native crayfish.

In a reconciled Delta, we propose a hierarchy to classify species as more or less desirable:

1. Species with the highest desirability are native species. Most are endemic—living only in the Delta or in California. They are therefore part of our natural heritage and part of what makes California a special place. Today's poorly appreciated native fish species, such as Sacramento splittail, may become highly desirable as food or sport fishes in the future, as cultural values change. Many native species are legally protected.
2. Next come alien species that are important sources of food or habitat for some native species (especially vertebrates), and that do not have many negative interactions with other native species and have habitat requirements compatible with those of native species. Many of these species are aquatic invertebrates. For example, most of the zooplankton (copepods, mysid shrimp, etc.) eaten by native fishes in the Delta are alien species. Actions that focus on improving habitat and food sources for native species will often benefit these alien species. (Likewise, improvements in the Delta ecosystem to favor native estuarine species will tend to favor alien fish species that have similar requirements, such as striped bass and American shad.)
3. Third are alien species that have direct economic value (e.g., for commercial and recreational fishing), but thrive in areas unfavorable to natives (e.g., various black bass, sunfish, and catfish species). Although management actions in a reconciled Delta should not focus on supporting these species, the future Delta will almost certainly retain large areas that favor them.
4. Last are alien species that are generally regarded as pests (e.g., Brazilian waterweed, mitten crabs, invasive clams). Resources will be required to limit the spread of such pests, given their harmful consequences to the ecosystem.

water quality standards, flows in the western Delta and Suisun Marsh are now tightly controlled. Rather than functioning as part of a tidal estuary, today's inner Delta functions more like a freshwater lake, while the outer Delta is more marine-like. Levees designed to protect farmland and urban areas from floods have partitioned the land, removing access of fish and other organisms to marshlands, seasonal floodplains, and riparian habitats. Habitat conditions vary less with the seasons, favoring invasions by alien fishes and invertebrates, which now make up most of the biomass within the Delta. Meanwhile, hatcheries—built to mitigate for effects of upstream reservoirs and to support commercial and recreational fisheries—have produced semi-domesticated salmon that compete with and interbreed with wild salmon, greatly reducing the viability of wild populations (Katz et al. 2012). In addition, Delta waters are laden with nutrients, harmful pesticides, and other contaminants from urban and agricultural wastes that can suppress food webs containing native fish and other desirable animals.

To support native fish species at different points in their lives, it will be necessary to reintroduce more structural diversity and flow and salinity variability in the Delta ecosystem, while limiting the harmful effects of contaminants, diversions, and invasive species (Moyle, Bennett, et al. 2010; Hanak et al. 2011; California Department of Fish and Game 2011; Delta Stewardship Council 2011). In particular, management must seek to attain seven objectives:

1. **Reconnect land and water.** Many of the Delta's native fishes use seasonally flooded riparian lands and tidal marsh for spawning and/or rearing and rely on nutrients originating from floodplains and marshes to support their food webs. Such habitats are now in short supply.
2. **Create a more favorable environmental flow regime.** Native species, especially fishes, evolved in response to a strongly seasonal natural flow regime (e.g., higher flows in the spring and early summer, coincident with the rain and snowmelt). Therefore managing timing, magnitude, duration, and frequency of inflows and outflows is important for such functions as cueing fish migration and spawning, eroding and depositing sediment to shape habitat, maintaining important salinity and temperature gradients, and transporting and cycling nutrients that support production of food for native fishes. Flow regimes resembling the historical natural flow regime are more likely to favor native fishes. However, given the altered conditions of the Delta landform and ecology, flows might need to depart in some respects from these historical patterns to accommodate the needs of native fish. For instance, today's altered landscapes may require proportionally higher flows at some locations and times to create seasonal floodplains, and non-natural flow patterns might sometimes be useful in suppressing now-dominant populations of invasive species.
3. **Improve water quality.** Water quality also plays a key role in creating functional habitats. The right amounts of nutrients such as nitrogen and phosphorous are needed to support the production of algae, which forms the base of most food webs. Delta nutrient loads are too high in some regions, leading to eutrophication and harmful algal blooms (e.g., Lehman et al. 2004). Additionally, sewage treatment plant discharges have altered ratios of different types of nutrients, particularly forms of nitrogen, altering the structure and productivity of food webs (Dugdale et al. 2006; Glibert, 2010). Finally, pesticides, herbicides, selenium and other compounds may be causing harm to some fish species in the Delta (Feijoo, Momo, et al. 1996; Feijoo, Garcia, et al. 2002). Reducing contaminant and nutrient discharge into the Delta, including restoring proper ratios of nutrients, is essential for improving ecosystem function.
4. **Connect functional habitats.** Fish require a sequence of habitats that support each stage in their lives, from spawning, to larvae, to rearing, to maturation. To provide support for each life stage, these habitats must be geographically and hydrologically linked. For some fish, these chains of habitat can extend well upstream of the Delta.
5. **Disconnect dysfunctional habitats and better isolate water used for human and ecosystem demands.** Managers have long recognized that canals and aqueducts do not usually provide good habitat for fish, so keeping fish out of such habitats with fish screens or other barriers is a common practice. The Delta has a special problem because the south Delta export pumps are large enough to

change the way water—and fish—move through the Delta. In theory, reducing direct water removal by these pumps (e.g., through peripheral conveyance) could improve conditions for fish, while also improving the reliability and quality of delivered water for human uses. Reducing pumping could reduce the cross-Delta movement of water that leads salmon and delta smelt into stressful or fatal conditions in the central and south Delta. Similarly, juvenile salmon and other fishes are drawn into Clifton Court Forebay, where they are subject to capture by the SWP pumping plant and heavy predation in the forebay itself (Kimmerer 2008).[5] Thus flow patterns that draw desirable species into unfavorable conditions should be blocked or reduced.

6. **Reform hatchery policies to favor native species.** Hatchery policies, aiming to support commercial and recreational fisheries, have decreased sustainability of wild native salmon and steelhead. Management of hatcheries needs to fundamentally change, by separating their production function for fisheries from their conservation function for native species protection and diversity (Moyle, Israel, and Purdy 2008; Katz and Moyle 2012; Lindley et al. 2007)
7. **Reduce new alien invasions and suppress the most harmful invasive species.** Threats from new invasive species are generally underappreciated until a species has arrived and is in an explosive growth phase. Although additional invasions are inevitable, prevention programs (e.g., for zebra and quagga mussels) can slow the pace of invasions and reduce the need to directly control harmful invaders (e.g., via biological, mechanical, or chemical means, as is currently done with Brazilian waterweed and water hyacinth). Sometimes, indirect control can be achieved by creating habitats unfavorable to invaders but favorable to natives (e.g., Kiernan, Moyle, and Crain 2012).

Guiding Principles

Several principles should guide Delta management as it seeks to meet these objectives. First, the most pragmatic and cost-effective approach to reshaping the Delta ecosystem is to harness the system's natural energy. Tides, river flow, and sunlight provide large amounts of energy to shape the Delta. Naturally occurring sediment and plant growth also provide material for shaping the Delta landscape. Allowing natural processes to perform as much of the work as possible is an economical and sustainable way to make changes in the Delta. To reestablish these natural functions, it will be necessary to make changes in levees and flows to help guide the dissipation of energy and the flows of sediment, salt, nutrients, and fish. The location and timing of these changes must be planned in a comprehensive and integrated manner, both to obtain the greatest benefits from the restoration of natural functions and to minimize the cost and disruption of these efforts.

Second, management plans will need to anticipate and prepare for future changes. Sea-level rise, climate change (increasing temperatures, more climatic variability, more extreme wet and dry events), changing inflows, new invasive species, continued farmland subsidence, earthquakes, and levee failures will occur. Many of these changes will require considerable preparation and changes in thinking. In some cases—such as flooding of subsided agricultural islands—these changes will provide opportunities for additional habitat and recreation, even though they will have undesirable economic consequences for those who farm and work those lands and will create habitat that mostly favors non-native species (e.g., Franks Tract).

Finally, because even the best plans will not anticipate all contingencies, it is necessary to prepare for surprises. A reconciled Delta will be a new ecosystem that is constantly changing, and our scientific

[5] Miller et al. 2011 provide a critique of this view.

understanding of that ecosystem will always be incomplete. Therefore, effective planning must prepare for a range of contingencies, including the unexpected. This type of sophisticated planning and response will require a strong scientific and technical program, capable of developing and implementing more effective actions as conditions change and understanding improves. Over-negotiating and over-specifying all details of ecosystem management up front could easily preclude effective adaptive management.

A Vision of a Reconciled Delta Ecosystem

You've got to be careful if you don't know where you're going because you might not get there.

—Yogi Berra

In our vision for a reconciled Delta ecosystem, habitats in different parts of the Delta would be specialized to foster improved conditions for native fishes. All forms of habitat cannot be at all locations, so we propose a strategy in which different habitat types are available and connected to support each desirable species at the appropriate season, taking advantage of existing ecological differences among different regions of the Delta. Area specialization can provide the ecosystem diversity and variability that native fishes (and other organisms) need, while supporting continued human uses of Delta land and waters.

In this section, we first describe the kinds of habitat that are beneficial for the Delta's native fishes and assess the likely suitability of different parts of the Delta to provide this habitat. Next, we discuss habitats that are less desirable. Then we lay out our vision for a reconciled Delta.

Where the Wild Things Want to Be

Different fishes have different requirements at different stages of their lives. Delta smelt and other open water, or "pelagic" fishes need open tidal waters, including shallows along beaches and riverine habitat for spawning (Table 3).[6] For these species to thrive, appropriate habitats for each life stage must be available, with migratory pathways that connect them to favorable habitats while minimizing their movement into unfavorable or high-risk habitats.

Many native fishes, such as tule perch, hitch, and juvenile salmon, need inshore areas with complex cover, cool, well-oxygenated water, and other characteristics that make these habitats less suitable for most alien species that now live in the Delta. Splittail, for example, use tidal brackish marsh for rearing (e.g., Suisun Marsh) but floodplains for spawning and larval rearing, and they must migrate annually between the two habitats. In general, native estuarine fishes prefer habitats with considerable seasonal and spatial variability in conditions such as temperature and salinity, while the predominant alien fishes now present, such as largemouth bass, prefer more stable conditions, with warm, fresh water in the summer. Such conditions tend to encourage dense beds of alien aquatic plants such as Brazilian waterweed, which is favorable habitat for alien fishes.

[6] Native longfin smelt falls into this category, as do the non-native striped bass and threadfin shad. Populations of all four species have been in sharp decline since the early 2000s, though there has been some rebound following this most recent, very wet year.

TABLE 3
Habitats of selected Delta fish species at different stages of life

Species	Migratory?	Spawning	Early life stages	Juvenile	Adult
Native species					
Chinook salmon	Yes	Rivers	Gravel in rivers	Rivers, tidal edge habitats; floodplains	Ocean
Delta smelt	Yes	Fresh water; sandy beaches(?)	Delta open waters	Same as adult	Fresh/brackish, cool, tidal water
Hitch	Partial	Floodplains, lower reaches of streams	Open waters of sloughs	Streams, open water in sloughs	Freshwater sloughs near rivers
Longfin smelt	Yes	Fresh water; beaches	Brackish/saline bays	Brackish/saline bays	Ocean, SF Bay
Splittail	Yes	Floodplains	Floodplains	Tidal brackish marsh	Tidal brackish marsh
White/green sturgeon	Yes	River, deep water	River, deep water	Riverine habitats	Entire estuary, ocean
Non-native species					
Largemouth bass & other sunfishes	No	Shallow areas near vegetation	Same as spawning	Same as adult	Vegetated Delta channels, warm
Striped bass	Yes	Lower reaches of main rivers	Open water river to Suisun Bay	Open waters Delta, Suisun	Entire estuary, open tidal waters, ocean
Threadfin shad	No	Riverine areas	Same as spawning	Same as adult	Backwaters and sloughs, warm
White catfish	No	Rip-rap, trash, and old trees	Near spawning habitat	Same as adult	Muddy, warm fresh-to-brackish sloughs
Yellowfin goby	Partial	Mud-bottomed salty areas	Same as spawning	Brackish water sloughs (e.g. Suisun Marsh)	Marine & brackish water bays

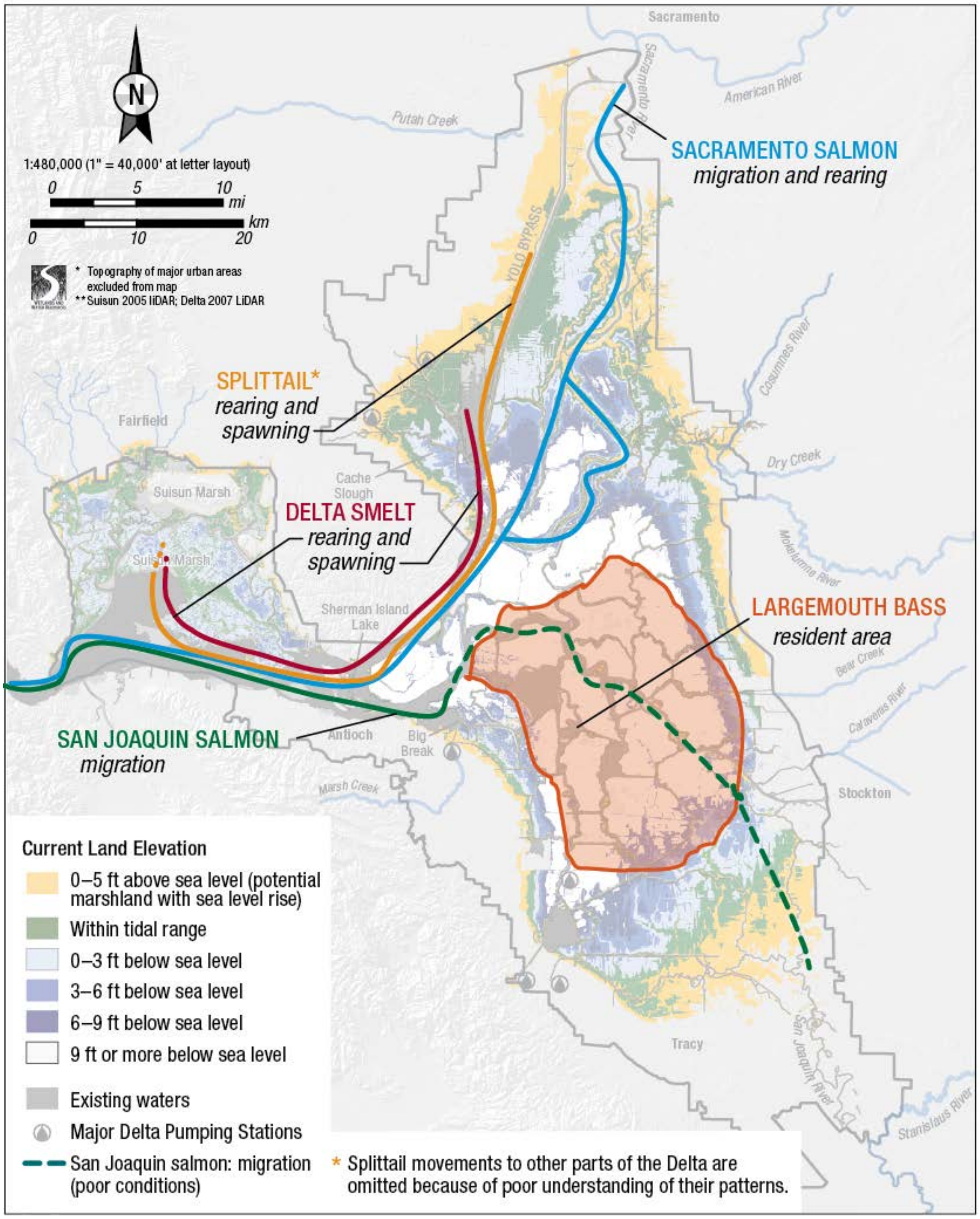
Current Habitats and Ecological Functions

Although much of the diverse historical habitat in the Delta has diminished, today's Delta still contains fragments of habitats essential for native fish species, along with large areas that are more hospitable for alien species. A reconciled Delta must expand and connect habitats that support native species, within the limits of what natural processes and current landscape shapes will allow.

Essential habitats for native species

Favorable habitats for native species today are primarily in the northern and western Delta, where the Sacramento River connects various freshwater and brackish habitats (Figure 2). The Sacramento River-Delta habitat arc consists of habitats from the Yolo Bypass (floodplain), the Cache-Lindsey Slough area (complex, cool slough habitat), to the Sherman Island "lake" (cool tidal slough habitat at the western edge of Sherman Island), and Suisun Marsh (brackish tidal habitat). Pockets of favorable habitat also exist further to the east, where there is influence from inflowing rivers such as the Tuolumne, Stanislaus, Mokelumne, and Cosumnes.

FIGURE 2
The northern and western Delta now provide the most favorable habitat for native fish species



SOURCE: Base elevation map adapted from Stuart Siegel, Wetlands and Water Resources, Inc., 2009.

NOTE: Colored lines indicate principal migratory routes through the Delta of each species.

Tidal marsh

Most of the Delta and Suisun Bay was once tidal marsh, with tidal flows varying across the system and considerable salinity variability in the Suisun Marsh and other far western Delta areas (Contra Costa Water District 2010). About 95 percent of this tidal marsh is now gone (Bay Institute 1998; Whipple et al. forthcoming). It is likely that biomass from marshes and floodplains (phytoplankton, detritus, bugs, zooplankton, invertebrates, and small fishes) fueled food webs in this complex habitat (e.g., with shallow tidal channels, fallen trees, branchlike sloughs, ponds), which formerly supported a diverse and abundant fish fauna.

Freshwater tidal marsh was the most abundant type of habitat in the Delta, and it was vital habitat for numerous native fish species. Only small, altered remnants of this habitat remain, in places such as Cache Slough and Steamboat Slough. In Suisun Marsh and the western edges of the Delta, seasonal *brackish* tidal marsh was prevalent. Significant areas of brackish marsh remain today in Suisun Marsh and nearby areas, such as in Big Break (a shallow inundated area at the Delta's western edge, created when a subsided island permanently flooded in the late 1920s).

Current land elevations and salinity levels make Suisun Marsh the most suitable place for large-scale, contiguous brackish tidal marsh restoration; this area will also be able to accommodate anticipated levels of sea-level rise (at least over the next century). Extensive freshwater tidal marsh restoration can be accomplished in the lower Yolo Bypass/Cache Slough region, the lower Sacramento River/Mokelumne River regions, and portions of the north Delta that have subsided less than one meter below sea level.[7]

In contrast, land elevations on the islands in much of the inner Delta have become too low to enable the re-creation of tidal marsh. Sediment—necessary for establishing and growing these habitats—is in limited supply, greatly reducing the chance of reclaiming these lands as terrestrial or intertidal habitat (Schoellhamer 2011). Also, the permanent flooding of these islands—increasingly likely from earthquakes, sea-level rise, and higher winter and spring flood flows—would reduce tidal energy, further limiting locations where tidal marsh functions can be supported in the future. As shown in Figure 3, hydrodynamic modeling suggests that permanent flooding of many subsided islands would substantially reduce tidal range throughout the Delta.

Seasonal floodplains

In pre-settlement times, vast riparian floodplains flanked the northern and southern edges of the Delta, and more modest floodplains existed on eastern tributaries. These seasonal floodplains, inundated by winter, spring, and early summer floods, drained directly into tidal freshwater marsh and channel areas or back into river channels before entering the Delta. These areas provided critical habitat for spawning and rearing of many fish species (Moyle 2002). The development of floodplains for urban and agricultural uses and the leveeing of rivers to protect these lands has greatly reduced this type of habitat. Some successful seasonal floodplain restoration has occurred in recent years by breaching levees along the lower Cosumnes and Mokelumne Rivers (Jeffres, Opperman, and Moyle 2008; Moyle, Crain, and Whitener 2007). Other areas with significant potential include parts of the Yolo Bypass and the lower San Joaquin River (Moyle, Bennett, et al. 2010).

Deep-water channels

Both the lower Sacramento River and the lower San Joaquin River contain channels that are 15 to 65 feet deep (including dredged shipping channels), surrounded in places by shallow, mostly non-vegetated shoals and minimal adjacent marsh habitat. Many reaches are confined by levees lined with rock (or "riprap"). These channels provide poor habitat for most fishes because of strong riverine and tidal

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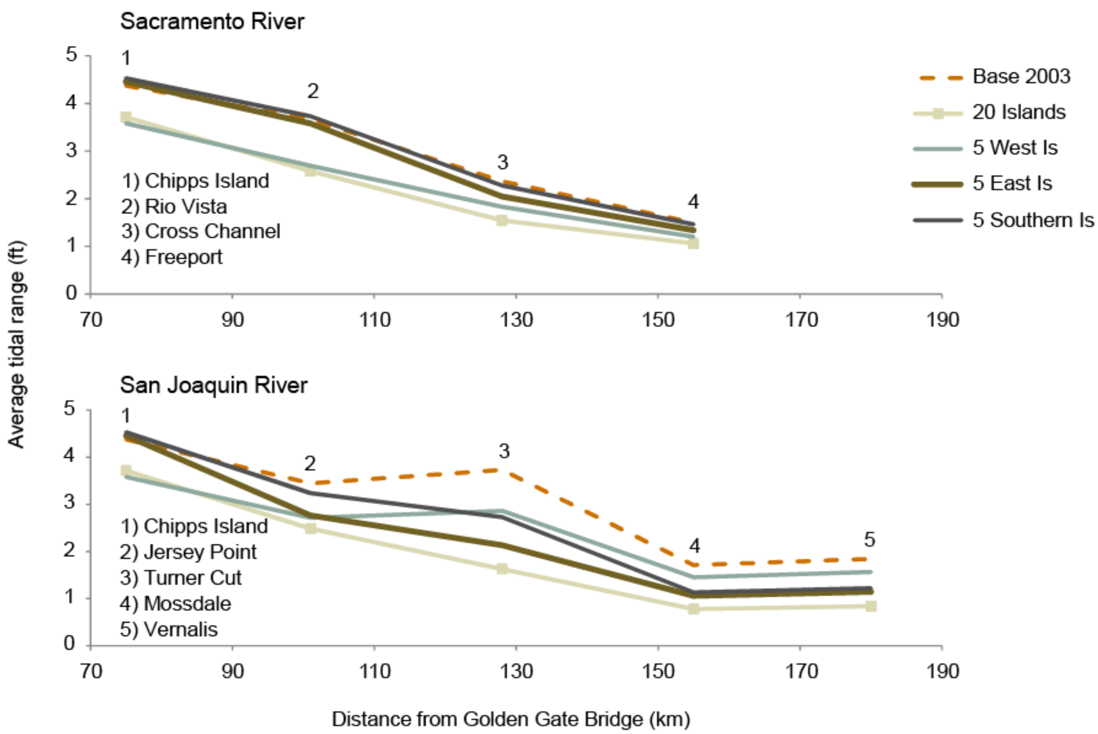
[7] See the light blue and green areas in Figure 1.

currents, combined with low structural diversity, especially on the San Joaquin River side. On the Sacramento River side, juvenile delta smelt and longfin smelt rear in deep channels and adjacent shoals during spring and early summer, before moving seaward to brackish adult rearing habitats. When the low salinity zone moves landward into the Delta, sub-adult delta smelt are centered in the lower Sacramento River and north Delta during summer and fall.

FIGURE 3
Extensive permanent island flooding could substantially reduce tidal energy, limiting capacity to restore tidal marshland



SOURCE: Calculations by William Fleenor using results from RMA Associates.

NOTES: The figure shows results from a two-dimensional hydrodynamic model (described in Fleenor et al. 2008) that examines the long-term effects of permanently flooding four sets of deeply subsided Delta islands for the water year 2003 (October 1 2002 to September 30 2003). Different flooding scenarios are shown with different colored lines. (For a map of the islands, see Fleenor et al. 2008). The model assumes unchanged hydrology and water operations.

Non-tidal marsh

Before the establishment of agriculture, non-tidal marsh or perennial wetlands and lakes were abundant on the floodplains upstream of the Delta, as well as in some areas of the Delta itself (Whipple et al. forthcoming). These marshes formed important habitat for a mix of riparian and aquatic plant and animal communities, and they provided critical habitat for migratory waterfowl, as well as habitat for native resident fishes such as Sacramento perch, thicktail chub, and Sacramento blackfish. Although there has been some development of managed wetlands to mitigate for the loss of natural wetlands, these managed areas are typically designed to serve mainly as refuges and breeding areas for waterfowl. For instance, much of Suisun Marsh is now managed as a series of discontinuous, intermittently connected, non-tidal marshes for waterfowl favored by duck hunters, especially mallards. Other managed wetlands now exist in the Sacramento and San Joaquin Valleys, mostly as state and federal wildlife refuges. The most promising area for expanding non-tidal marsh to support a broader range of species is in the lower San Joaquin River (roughly from Interstate 5 to Highway 4), perhaps as part of a San Joaquin River bypass system for flood management.[8]

Riparian forests

Extensive riparian forests and other habitats once bordered the rivers feeding into the Delta. The forests continued along naturally occurring levees of these rivers and associated channels, extending well into the Delta, particularly along the Sacramento River. Riparian forests provide critical habitat for numerous terrestrial species. This habitat also supports aquatic species, principally by providing physical complexity and large wood to the system, as well as carbon inputs that support the food webs that include juvenile fishes. Riparian habitat requires frequent disturbance from floods and channel migration. Successful restoration of this habitat will require setting back and breaching levees to restore dynamic conditions. Portions of the Sutter Bypass, the lower San Joaquin River (roughly from Interstate 5 to Highway 4), and Delta tributaries such as the Cosumnes and Mokelumne Rivers are promising areas for riparian habitat.

Novel, less favorable habitats for native species

Today, the Delta has several forms of habitat that are far less favorable to native species, including deep tidal "lakes"—the result of permanent flooding of deeply subsided islands—and hardened canals and channels—the result of land reclamation and flood control efforts.

Flooded islands

Two deeply subsided flooded islands exist in the central Delta: Franks Tract (6–8 feet) and Mildred Island (10–15 feet) (Lucas et al. 2002). Although these deeply flooded islands experience tidal influence, they resemble freshwater lakes because they provide still-water habitat that favors alien lake species from the eastern and central United States. For example, non-native largemouth bass and sunfishes (*Lepomis spp.*) are abundant in Mildred Island and Franks Tract, which are dominated by invasive aquatic vegetation, freshwater alien invertebrates, and other alien fishes (Nobriga and Feyrer 2007; Hestir 2011). It is likely that additional island flooding and abandonment will create much larger areas of such lake-like habitat in the future, especially in the low-elevation areas of the south-central Delta.

In contrast, Liberty Island is a shallower flooded island (mostly 1–4 feet) located in the northwestern Delta, near the Yolo Bypass. Liberty Island tends to be more turbid, it is largely devoid of submerged aquatic vegetation that supports undesirable non-natives, and it is dominated by flows and low water temperatures that are well-suited to native fishes and discourage alien species. Few opportunities exist for additional island floods that offer such useful shallow habitat for native fishes, with the exception of islands along the northern, eastern, and southern edges of the Delta (Figure 1).

Hardened channels

The Delta's channel network is defined by hundreds of miles of levees, all but a handful of which are lined with riprap and cleared of vegetation. These hardened canals and channels have become the most common

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[8] This most favorable area is shown below in Figure 4. Tidal influence in this area is likely to diminish over time with island flooding and the redevelopment of tidal marshland in Suisun Marsh and other areas in the western Delta (Figure 3).

shoreline habitat in the Delta. Unlike the Delta's natural channels before the marshland was diked and drained to create farmland, these artificial channels lack hydraulic connections to tidal marsh and floodplain habitat. Where low-velocity and backwater areas occur with these channels (particularly in the south and central Delta), extensive beds of non-native submerged aquatic vegetation develop and support a suite of non-native species such as largemouth bass, sunfishes, various catfishes, and red swamp crayfish. Although desirable pelagic and migratory fishes (including smelt, salmon, sturgeon, pikeminnow, and striped bass) also use these channels extensively as corridors when moving along their habitat chains, the channels provide them with relatively low-value habitat: The channels are disconnected from (and lack exchange with) tidal marsh and floodplain habitat, they are strongly influenced by water project operations, and they harbor numerous non-native predators.

A Reconciled Delta

The Reconciled Delta we propose is founded on a coherent, robust, and dynamic portfolio of habitats and flows that support desired ecosystem functions and conditions. Decades from now, the Delta will have several functionally different habitat areas, largely determined by their elevations (Figure 4). How well these areas support desirable groups (or "assemblages") of species will depend on how we manage them. The lowest, most tidal portions of the Delta and Suisun Marsh influenced by the Sacramento River would be managed for estuarine species, which thrive under significant tidal and seasonal fluctuations in salinity, flow, temperature, and other factors (e.g., delta smelt, tule perch, striped bass). Some parts of the Yolo Bypass to the north would be managed to support fish that thrive in floodplains and complex riverine habitats (e.g., Chinook salmon, splittail, Sacramento hitch) connected to migration routes to San Francisco Bay. Lower portions of the eastern streams and the San Joaquin River would be managed for riparian species and salmon. The central Delta—likely to contain more deep-water "lakes" than it does today—would be maintained for non-native recreational species. Because this area is problematic as habitat for native fish species (depending on temperatures and salinities), it would need to be separated, perhaps with diked corridors, to avoid drawing salmon and other native fishes into it.[9]

Urban and high-valued agricultural areas throughout the Delta would continue to be protected, with levees repaired after flooding. Any urban expansion would need to address flood safety with future conditions of higher sea levels and higher winter and spring flood flows. Valuable road, rail, aqueduct, and energy infrastructure would also be protected from flooding.[10] Urban development would also be avoided in locations that are important for expanding tidal marsh and floodplain habitats or that are particularly sensitive to urban runoff.

Here, we describe key characteristics of the different habitat areas displayed in Figure 4.

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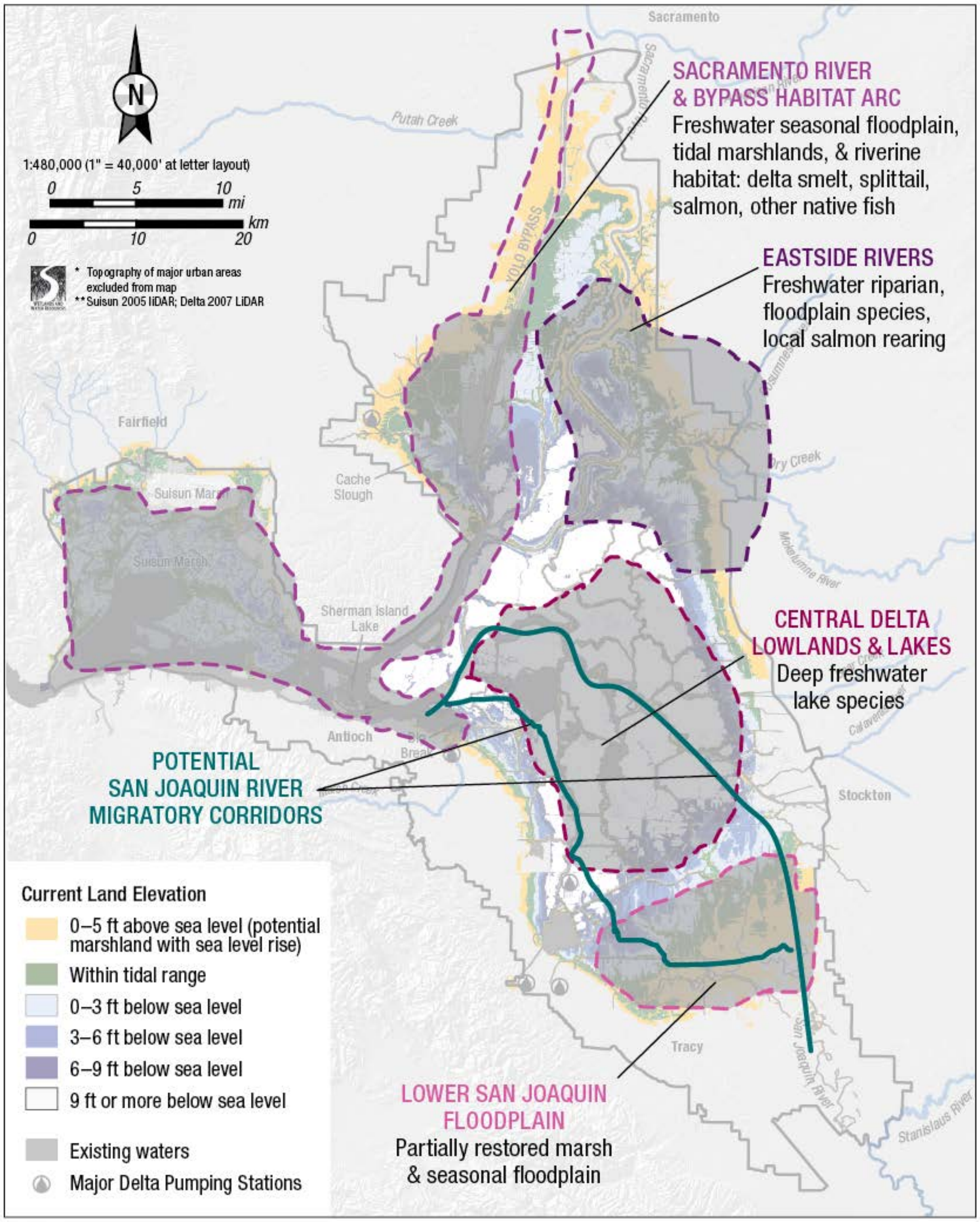
[9] Separate migration corridors might be more difficult on the San Joaquin River, but might be more easily accomplished along a southwestern arc through the Delta, especially if exports from the south Delta pumps are diminished.

[10] Options include consolidating such infrastructure in more easily protected corridors or modifying it to make it more resilient (Lund et al. 2010). For example, road and rail crossings may need to be raised and reinforced, and gas pipelines and the Mokelumne aqueduct might be buried to provide security from levee failures.

FIGURE 4
A reconciled Delta ecosystem will have specialized ecosystem areas and connecting corridors



SOURCE: Base elevation map adapted from Stuart Siegel, Wetlands and Water Resources, Inc., 2009.

NOTE: This map shows ecosystem areas as regions. As described in the text, these regions would continue to support most urban and agricultural land uses as well as transportation functions. Islands within the central Delta whose economic value (including for strategic uses like roads and rail lines) justifies the expense would continue to be protected.

Sacramento River and Bypass Habitat Arc

The western and northern Delta and Suisun Marsh habitat areas would become more specialized to support native species and recreation, with substantial remaining agricultural lands and managed wetlands. Together, these areas would form a tidally connected arc of habitats tailored to support delta smelt, splittail, and salmon.

Large contiguous areas of Suisun Marsh would become brackish tidal marsh with specialized uses reflecting present conditions, much like the Delta. With sea-level rise, some parts of the Marsh (especially the southern fringes) would become inundated and largely subtidal, while others (e.g., the northwestern areas) would likely remain as diked, if increasingly brackish, non-tidal marsh. Connections between Suisun Marsh and the larger Delta ecosystem would improve, facilitating species movements.

Some agriculturally marginal lands in the northwestern Delta would return to tidal marshland (e.g., Prospect Island and parts of the lower Yolo Bypass). Parts of the lower Yolo Bypass would be managed to flood more regularly, with better connections between the floodplain and the larger aquatic ecosystem. Tidal marsh habitat would extend along this corridor, allowing estuarine gradients in salinity and other water-quality characteristics that support native fishes to exist over a wider range of seasons and water year conditions.

The Big Break and western Sherman Island areas form a potentially important part of this habitat region, linking the northern Delta with Suisun Marsh and Suisun Bay. The Sherman Island slough complex, for example, supports a diverse fish fauna including abundant native fishes such as tule perch, hitch, prickly sculpin, and splittail (unpublished data, M. Young, UC Davis, 2010-2011). This complex slough system receives continuous freshwater flows from the Sacramento River, as well as tidal flows from Suisun Bay.

The Sacramento River and Bypass Arc has the greatest potential to support native estuarine species in the next 10–30 years. The portfolio of habitat locations, arranged along the axis with greatest tidal influence, can support gradients in salinity and turbidity for a wide range of tidal, seasonal, and interannual time scales. As sea level rises, it should be able to accommodate salinity-based changes in habitat (e.g., more-saline tidal marsh habitat in Suisun Marsh). This corridor also allows creation of these habitats with relatively little disruption to other uses. There will be some land use tradeoffs, including reversion of some diked wetlands in Suisun Marsh to tidal wetlands, and farmlands in the north and western Delta and Yolo Bypass to marsh or seasonal floodplain.

Warming water temperatures may constrain habitat supported by this corridor. In particular, temperatures in shallow parts of the western Delta where delta smelt congregate for part of the year appear quite sensitive to warming air temperatures, and summer temperatures are often close to the upper limits that the smelt can tolerate (Moyle and Bennett 2008). Expanding the tidal marsh areas within Suisun Marsh can help to manage this problem. Night time high tides during the warm summer months increase surface area and allow fog and winds to keep Suisun Marsh cooler.

For salmon and steelhead, maintaining sufficiently cool water temperature upstream of the Delta will be increasingly challenging, with diminishing availability of cold water pools in upstream reservoirs and increasing needs to release cold water to maintain cooler temperatures downstream (Cloern et al. 2011; Hanak et al. 2011, chapter 3). These releases could pose increasing tradeoffs between water for environmental flows and urban and agricultural uses unless there is adequate capacity to export and store water downstream of the Delta for later use. The continued adequacy of cold water for upstream habitat will also be an issue for migratory fish in two other specialized parts of the Delta, the Eastside Rivers and Lower San Joaquin Floodplains areas.

Eastside Rivers

The eastern and northeastern edge of the Delta would be specialized into tidal marsh, riparian, seasonal floodplain, and non-tidal marsh habitats; considerable agriculture could continue as well. The centerpieces of this transition are the Cosumnes and Mokelumne river corridors, connecting the restored floodplains of the Cosumnes Preserve with new tidal marsh, riparian, and floodplain habitat below the Cosumnes/Mokelumne confluence. This strategy uses freshwater river flows from the unregulated Cosumnes River to provide the hydrologic variability and sediment needed to sustain these habitats. This grouping of habitats, largely separated from the most tidal portions of the Sacramento River and Yolo Bypass, will serve mostly freshwater riparian species and locally migrating salmon. Wildlife-friendly agriculture, supporting bird species such as sandhill crane, would continue on Staten Island and portions of the Cosumnes Preserve.

Much of this transition is already under way. A major obstacle is the depleted groundwater basin under the lower Cosumnes River, which draws enough water from the river to preclude salmon migrations in some years. Addressing this problem will likely require reducing local agricultural water use or providing long-term substitute sources, such as recycled water from wastewater treatment plants or augmentation of shallow groundwater from nearby rivers (Fleckenstein et al. 2004).[11]

Lower San Joaquin Floodplains

Today, the San Joaquin River upstream of Highway 4 is narrow and channelized, with little flow and high concentrations of agricultural drainage and urban wastewater. It could be broadened into a non-tidal brackish marsh and seasonal floodplain supported by brackish flows from the San Joaquin River. The expanded habitat areas would primarily support waterfowl, serve as rearing habitat for San Joaquin basin salmon, and reduce nutrients entering the south Delta. To provide safer passage of salmon through the inhospitable central Delta, levees and gates could be used to create a migratory corridor, with strong currents, toward and from the western Delta. In addition, sufficient flows would be needed to prevent the formation of harmful algal blooms, particularly of *Microcystus.* This habitat expansion would also improve flood management for the lower San Joaquin River, with benefits to communities in the Stockton–Lathrop region. Substantial agriculture would continue in the area.

Without changes in regulatory policy governing upstream diversions and agricultural discharges into the San Joaquin River, low, warm, saline (including selenium) and nutrient-rich flows from this source will remain a major problem for native species in this area.[12] Such policy changes would also benefit local in-Delta agriculture.

Central Delta Lowlands and Lakes

Today, the Delta's deeply subsided core largely consists of agricultural islands, with riprapped levees lining the channels that separate them. From an ecological perspective, the central Delta is, and will likely continue to be, especially favorable habitat for alien freshwater lake fishes, such as largemouth bass, that are valued for recreational fishing. An important consideration for the reconciled Delta is reducing the burden this area places on migrating native fishes. Historically, the transport of water from the Sacramento River to the south Delta pumps, and the operation of the pumps themselves, has drawn salmon and smelt into the interior channels of the Delta, where they become lost or eaten by predator fish. Recent modifications to CVP and SWP operations, required by new biological opinions, have reduced capture. Flow barriers, leveed corridors, and a new conveyance facility that draws exports around or under the Delta could be especially useful in further diminishing this problem.

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[11] In fall 2006 the Bureau of Reclamation augmented flows on the Cosumnes River using the Folsom South Canal. By recharging shallow groundwater beneath the river, they improved natural flows in the river, enhancing passage for fall-run Chinook salmon. This experiment was not repeated in subsequent years.

[12] Such changes could occur with revisions to the Water Quality Control Plan for the Bay-Delta, under the purview of the State Water Resources Control Board (SWRCB). The SWRCB is currently assessing San Joaquin River flow and southern Delta water quality objectives as part of its review and update of the 2006 plan. (http://www.swrcb.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/water_quality_control_planning/).

Any such strategy will need to anticipate changes in the landscape of this area. Land and asset owners are likely to abandon some of these islands when they flood because the costs of repair and recovery often outweigh the value of economic activity and infrastructure on the islands (Suddeth, Mount, and Lund 2010; Medellín-Azuara et al. 2012). The remnant levees on flooded islands will provide shallow water habitat and wave barriers, and the islands themselves will create large areas of deep, open water habitat. Although such habitat is generally not well-suited for desirable species, the potential should not be ruled out (Moyle 2008). Among existing deepwater flooded islands, Mildred Island differs ecologically from Franks Tract. Understanding the differences through a program of adaptive management and active experimentation may provide opportunities for deriving useful habitat for native and recreational species from these areas in the future. For example, some islands could be managed (e.g., through partial levees) to favor the more pelagic (open-water-oriented) striped bass (compatible with some native fishes) over the more benthic (bottom-oriented) largemouth bass.

As noted above, flooded islands may also reduce the tidal amplitude in much of the Delta, with the greatest effects likely in the portions of the western, central, and northern Delta that currently have large tidal ranges (Figure 3). This is another reason to use leveed corridors and channels, to concentrate limited tidal energy where it will be most beneficial. The long-term result could be a habitat network of tidal and non-tidal lakes connected by channels and levee breaches.

The quality and quantity of San Joaquin River flows introduce major water-quality problems for this area. Water quality would likely decline as artificial cross-Delta flows from the Sacramento River are reduced, unless San Joaquin River flows are increased and nutrient and toxic discharges into the river are reduced either at their sources or in new wetlands along the lower San Joaquin River.[13]

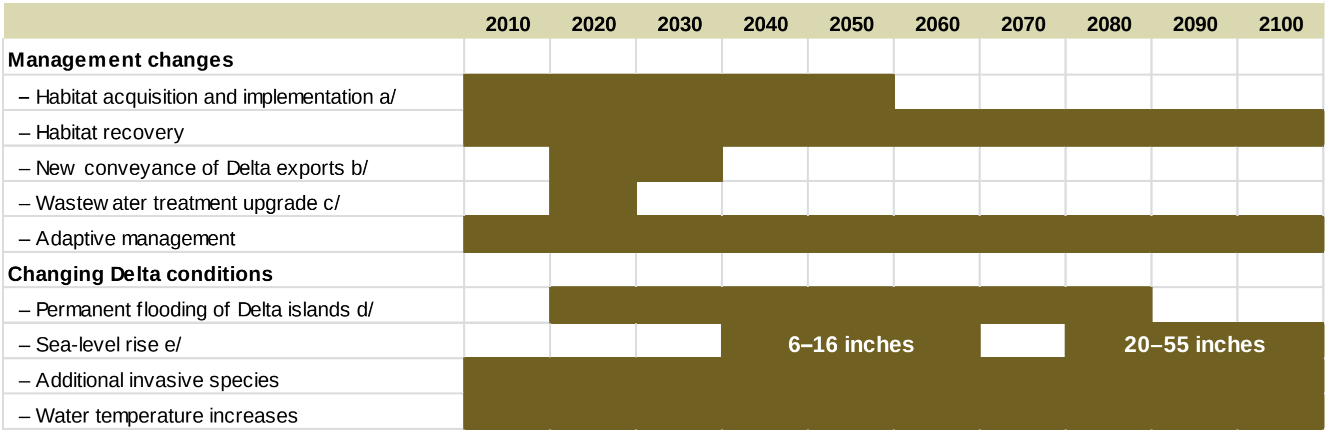
The ecological characteristics and management challenges of flooded islands remain one of the greater uncertainties for successful ecosystem reconciliation in the Delta. A robust adaptive management program, including experimentally flooding some islands, will be necessary to manage this novel habitat.

Reconciliation Is a Long-Term Process

This vision of a reconciled Delta cannot happen overnight. Although some benefits can occur in the near term, deliberate management changes will take decades to implement and even longer to become fully effective (Figure 5). For instance, the acquisition of areas appropriate for habitat expansion could stretch out over several decades, and the recovery of functional tidal marshland on these lands could take additional time (Moreno-Mateos et al. 2012). Likewise, the introduction of a new conveyance facility for water exports, which can provide greater flexibility in flow management, is not likely to occur for at least another decade or two. Upgrades of urban wastewater plants (e.g., the Sacramento regional wastewater facility) to reduce nutrient loads will also take a decade or more.

[13] In some months, agricultural and wastewater discharges now provide the main flows in the river.

FIGURE 5
Reconciliation will need to accommodate changing Delta conditions



NOTES: The figure depicts decades in which the changes are likely to occur.

a/ Timeframe of potential habitat acquisition as part of the Bay Delta Conservation Plan (2009).

b/ Author estimates. The earliest a new conveyance facility is likely to be operational is in the late 2020s.

c/ Assumed implementation of upgrades to Sacramento regional wastewater treatment facility.

d/ Based on flooding probabilities calculated in the DRMS study (URS Corporation and JR Benjamin & Associates 2009), many Delta islands will have flooded at least once by 2050. Some might not be worth repairing given the costs of repair and the value of economic activity on the islands (Suddeth, Mount, and Lund 2010).

e/ Estimates based on Vermeer and Rahmstorf (2009).

Meanwhile, the Delta will be changing in ways that require management responses (Figure 5). Sea-level rise, island flooding, and warming water temperatures are all ongoing, and the risks and potential consequences of each should be factored into planning for a long-term vision. Other changes, such as the inevitable arrival of new invasive species, will impose new, less predictable constraints. Finally, there is still much to learn about how species are likely to respond to the new, evolving ecosystem. We now turn to consider these management tools and approaches and the types of research and experimentation that will need to accompany a reconciliation strategy.

Management for Reconciliation

Managing for reconciliation will require orchestration of a wide range of activities, some familiar and others less so. It will also require a rigorous, sustained program of modeling, experimentation, monitoring, and adaptive management, as well as reliable and adequate funding. Here, we consider management activities needed to achieve a reconciled Delta ecosystem and the types of coordinated scientific efforts needed to facilitate successful adaptation over time.

Management Tools for Reshaping the Delta

The vision of area specialization outlined above rests on converting some existing farmlands and duck clubs to a network of tidal and non-tidal marshes and seasonal floodplains. Flows and flow-related infrastructure (especially levees and channels) would be altered to support these new habitat areas and the connections between them. Other tools include direct management of polluted discharges and species (Table 4).

The orchestration of these tools in an environment of change and uncertainty will require broad and insightful use of modeling to identify, test, and refine promising strategies. As in finance, business, and engineering, such calculations are a relatively inexpensive and often effective way to explore solutions before making major investments. Modeling will also require better data and analytical capabilities, as well as field experiments.

TABLE 4
Management tools for a reconciled Delta ecosystem

Management tools	Examples
Flow management	
Reservoir operations	Base, seasonal, bypass and pulse flows
Pumping and diversions	Diversion timing, location, facility type, and constraints on flow volumes
Landscape alteration	
Flow-related infrastructure	Levees, dams, operable and fixed barriers, fish screens, channel geometries that affect water flow and aquatic interaction with the landscape
Land use	Zoning, restoration actions for agricultural and urban uses, floodplain, tidal marsh, non-tidal marsh, deep water, rip-rap channel, and upland habitats
Land elevations	Land subsidence reversal (e.g., planting tules)
Water-quality management	
Treatment	Upgrading urban wastewater and stormwater treatment facilities, best management practices (BMPs) for nonpoint source control and quality
Capture and reduction	Capture and spreading or recycling of stormwater and agricultural discharges; reduction in loads (e.g., reduced applications of agro-chemicals)
Direct species management	
Harvest	Commercial and recreational fishing practices
Supplementation	Hatcheries to support commercial harvests or native species' genetic diversity
Suppression	Mechanical, chemical, physical techniques to suppress invasive species

Flow management

Flows are often considered the "master variable" in environmental management of the Delta (National Research Council 2012). A strong pattern of seasonal and interannual variability in flows is a defining characteristic of the Mediterranean climate in which the Delta's native species evolved. The dynamic interaction of flows with the landscape establishes the foundation for all other processes in the aquatic environment. Tidal flows dominate the complex, two-way mixing of salt, sediments, nutrients, and species in the western parts of the estuary. Farther upstream, river flows provide essential inputs of freshwater and sediment into the system and connectivity to seasonal wetlands. Higher flows may also dilute concentrations of harmful contaminants and reduce their residence time.

In the century and a half since statehood, changes in land use to support agricultural and urban development and changes in water management to support agricultural and urban water uses, navigation, and flood protection have diminished the seasonal and interannual variability of flows within the Delta and its watershed, in effect simplifying a once complex system. A key to restoring natural ecosystem functions—a central part of a reconciliation approach—is to reintroduce some of the variability in flows that better supported native aquatic habitat. The concept of restoring elements of the natural flow regime in river and estuarine systems is well-established in ecological theory and management (Dudgeon et al. 2006; Richter et al. 1996; Carlisle, Wolock, and Meador 2010).

It would be premature for this report to prescribe specific flow targets. Rather, we highlight some key issues that will have to be addressed in on-going and future planning efforts, such as the BDCP and the review and update of the Water Quality Control Plan by the SWRCB.

To support desired ecological functions in a reconciled Delta, a promising approach is to manage major inflows and diversions seasonally and across years in ways more consistent with key elements of the historical hydrograph (Fleenor et al. 2010). The benefit of restoring a flow regime that has these elements is well-documented in river systems (e.g., Poff et al. 1997; Poff et al. 2010; Poff and Zimmerman 2010; Carlisle, Wolock, and Meader 2010). However, flow regime restoration in estuarine systems is less well understood owing to the complexity of interactions between tides and rivers (e.g., Alber 2002; Flemer and Champ 2006; Goecker et al. 2009). Thus, development and implementation of any flow strategy would require coordinated experimentation over decades and have to accommodate climate change as well as physical changes of the Delta from habitat restoration or island flooding.

Today's approach to flow management is generally tied to the water year type, with monthly allocations of a percentage of the unimpaired flow to specific uses during that year. In a future, reconciled Delta, flow management will have to become much more flexible, take place on shorter time steps, and account for hydrologic conditions spanning many years.

For example, across years and seasons, flow management would provide for multiple and variable flood pulses in the Yolo Bypass, the eastside river floodplains, and the Lower San Joaquin River floodplain. Rather than occurring every year, these pulses would take advantage of hydrologic conditions, allowing drier conditions or no flooding at all in some years. Timed correctly, this variability would support native species habitat while disrupting the more stable conditions favored by invasive species. Multi-year flexible environmental flow management will also be critical for managing droughts, particularly if future droughts under climate change exceed observed historical droughts (e.g., the six-year duration that water managers currently use for planning).

A key operational consideration is whether water exports will continue to be drawn entirely through the Delta as currently practiced, or whether an isolated facility will be used to convey water from intakes on the Sacramento River to the export pumps in the south Delta. This facility could be sized and operated in two ways: as the sole source of water exported from the Delta, or as a "dual conveyance" system that withdraws water both from the existing export facility in the south Delta and from intakes on the Sacramento River. If properly designed and operated, a tunnel under the Delta or a canal around its periphery would provide increased flexibility in the operation of diversions, increasing the compatibility of water exports with ecosystem management. To date, however, there have been insufficient descriptions of operational criteria of an isolated or dual conveyance facility to assess its potential for ecosystem reconciliation.

In a reconciled Delta with either dual conveyance or sole reliance on an isolated facility, seasonal flow patterns might change as follows:

- **Spring**. High inflows to the Delta from the Sacramento and San Joaquin rivers during the spring are desirable for cueing juvenile salmon out-migration and adult spring Chinook upstream migration, as well as for flooding floodplain habitat for splittail spawning, salmon rearing, and other springtime ecological functions. Because excessive springtime export diversions from the south Delta pumps disrupt the migration of estuarine fishes and may be responsible for significant entrainment, upstream diversions would be favored during this time, if associated with real-time fish monitoring that allowed for rapid changes in diversions for short periods when needed. Major uncertainties include whether upstream diversions will increase predation or entrainment losses for out-migrating salmon and whether there is an optimal frequency, timing, and duration of spring releases to avoid such impacts.
- **Summer**. Summer Sacramento River flows provide the Delta with flow volume and higher quality (less saline) water. To improve water quality in the lower San Joaquin River, summer flows from this river would need to be higher and/or contain less agricultural or wastewater discharge. Exports could occur through both upstream and south-Delta diversion points during this period.
- **Fall**. Both the Sacramento and San Joaquin rivers will need sufficient flows to attract returning salmon (although a system of gates or barriers in the central Delta might limit the flow increases needed for this purpose). In some years, additional flows may be needed to keep the low-salinity zone downstream, depending on how well other measures—such as habitat restoration and flexible flow operations—work to sustain native fishes. The relationship between habitat improvements and flows remains a fundamental uncertainty requiring adaptive management.
- **Winter**. Historically, flood pulses from winter rains inundated critical late-winter habitat for rearing juvenile salmon, particularly on the Sacramento River. These flows still occur on the Cosumnes River. The best opportunity for restoring these floodplain flows elsewhere is on the Yolo Bypass, where modifications to the Fremont Weir, coupled with timed reservoir releases, can reestablish winter floodplain connections. Such changes will not necessarily require any reductions in water availability for downstream human users. Nor will they require large reductions in farming activities within the Bypass, since many activities are already compatible with winter flooding. San Joaquin River flow needs during this season require further investigation. The ecological benefits of winter flooding on the San Joaquin are a major uncertainty.

Ecosystem reconciliation in the Delta will be more difficult without some suitably operated form of isolated conveyance (Lund et al. 2010; Hanak et al. 2011). Even with operational improvements such as those introduced with the new biological opinions, water exports will continue to risk fish entrainment in the south Delta pumps. In addition, large volumes of exports from the south Delta will continue to disrupt internal flow directions and concentration gradients from their natural conditions, with negative implications for nutrient and biomass flows and fish cueing.

Islands, levees, barriers, and channels

The physical features and infrastructure of the Delta—including natural and modified islands, levees, channels, and gates—are also essential components of ecosystem reconciliation. Although the primary purpose of these structures is most often to support human activities—notably flood protection, navigation, and water quality—they have important consequences for the ecosystem by steering flows, sediment, nutrients, aquatic species, and tidal energy toward some areas and away from others. They also affect the frequency of inundation and connection between land and water, which can help support habitat such as tidal marsh. Physical barriers and channels also directly affect fish movements. Flows of water carry or cue fish at various life stages; and levees, barriers, gates, and channels can help to steer native fish toward or away from inhospitable parts of the Delta.

Deliberately managing environmental flows with such structures is not entirely new. For instance, gates on the Delta Cross Channel at Walnut Grove were installed in the early 1950s to facilitate flows of fresh Sacramento River water to the export pumps in the south Delta. At times, these gates are operated to maintain higher freshwater flows on the mainstem of the Sacramento River for the benefit of native fishes, mainly salmon. The reconciliation strategy called for here implies the need to explore and develop new, experimental ways of using these structures to meet multiple environmental objectives: managing flows and the tidal energy needed to develop vital habitat and separating habitat areas and corridors for estuarine species from those for riparian and deep-water lake species.

Some potential changes, such as barriers to keep Sacramento and San Joaquin river salmon out of the central Delta, could adversely affect the quality of water for local agricultural uses and water exports. The operation of barriers, connections, and gates would also have implications for recreational boating. The relative costs and benefits of these tradeoffs, as well as ways to avoid or to lessen such conflicts, would require additional study.[14]

Land conversions

The habitat management strategies described above cannot succeed without converting some lands now used for other purposes to tidal and non-tidal marshland and seasonal floodplains. Some additional upland habitat, with wildlife-friendly agriculture, will also be needed to support native birds and other terrestrial animals and plants. Habitat acquisition has been a central part of policy discussions regarding the Delta ecosystem for many years. The Delta Vision Blue Ribbon Task Force (2008) set a target of 100,000 acres of protected and restored habitat within the Delta and Suisun Marsh. The BDCP has set an even higher target—up to 113,000 acres—including as much as 32,000 acres of agricultural lands managed to benefit endangered species (Bay Delta Conservation Plan 2010).

In the rush to improve environmental conditions in the Delta, there is a danger that policymakers are focusing more on the quantity of new habitat than on its quality and location.[15] It will be essential to select areas that can support the desired ecological processes, taking into account not only land elevations, but also access to appropriate flows, sediment, nutrients, and tidal energy. Because land conversions have direct economic consequences for landowners and local communities, they will require compensation, as discussed below.

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[14] One alternative might be to create a separate corridor, using barriers and gates, for through-Delta exports, to facilitate the separate management of flows for export and ecosystem purposes. Mitigation options might be explored for those agricultural water users within the Delta whose yields were affected by higher salinity.

[15] To date, we are unaware of a scientific justification for the acres of proposed habitat.

Water quality

Water quality in the future Delta will vary with a number of factors, including flow management, regulation of urban discharges and agricultural drainage, and the physical structure of the upper estuary. The salinity of San Joaquin drainage is a concern for the ecological viability of the Lower San Joaquin floodplains and channels; this drainage also will have increasing consequences for the Central Delta Lowlands and Lakes area. Other important concerns are likely to include salts from the ocean, pesticides and nutrients from urban and agricultural users, sediment imbalances, and the interactions of water quality with landscapes, flows, and invasive species. Improving the understanding of these factors, as well as their interactive effects, will require extensive modeling, data collection, and experimentation.

In addition to manipulating flow volumes and directions, tools for direct management include additional treatment of urban wastewater and stormwater, capture and spreading or onsite reuse of polluted agricultural drainage, and reduction of pollutant loading (e.g., reducing excess pesticide and nutrient use on farms and urban landscapes). Because each of these solutions entails costs for dischargers, it is important to consider their potential effectiveness in reducing ecologically harmful pollutants. For some contaminants, such as salts and nitrates, pollutant trading on specific reaches of rivers may help achieve some desired outcomes at lower cost (Hanak et al. 2011).

Direct species management

Most discussions of the Delta ecosystem focus on indirect management of species by altering habitat and flow conditions. Direct management of aquatic species has long been part of environmental management, and it can have an important role in a reconciliation strategy. Current activities include the use of hatcheries to support salmon fisheries and to preserve wild genetic diversity of delta smelt, regulations to prevent commercial and recreational overfishing, and suppression of invasive plants and animals by mechanical harvesting or chemical means.

Where effective, actions to suppress invasive species would likely continue in a reconciliation strategy. In contrast, salmon hatchery management would need to change. State and federal hatcheries in the Central Valley currently try to serve two conflicting purposes: sustain commercial and sport fisheries and support conservation of salmon stocks (Moyle, Israel, and Purdy 2008). Unfortunately, the domestication process that occurs in hatcheries produces genetically uniform strains of fish (most notably for fall-run Chinook) that have high rates of straying to other rivers, where they spawn with or displace remaining wild salmon (Katz et al. 2012). Hatchery progeny have lower rates of survival, which hatcheries overcome by producing millions of small salmon regardless of return rates of the fish from the ocean. As a result, hatchery and "wild" fish are increasingly the same both genetically and behaviorally, largely eliminating adaptations to local streams and leaving distinct salmon runs vulnerable to genetic bottlenecks, disease, and changing environmental conditions to which they will be unable to adapt.

Reversal of this trend will require separating the conservation and production functions of hatcheries. One way would be to drastically reduce (or eliminate) hatchery production and only allow fish that were progeny of wild-spawned fish to spawn in rivers, under the assumption that natural selection would provide for better-adapted wild fish. This strategy would entail shutting down the fishery for decades and having many fewer fish available under the best of circumstances (because dams would likely continue to cut off access to most spawning habitat). Another way to achieve functional separation would be to rear all hatchery juveniles in cages in the estuary until time of release, when they would be marked. If done right, most adults would return initially to the vicinity of the cages, where they could be the focus of a terminal commercial fishery. Hatchery fish that escaped upstream would be subject to the sport fishery and excluded, by weirs, from key spawning areas. This strategy could be enhanced by using strains of salmon adapted to more northern river systems, greatly reducing the likelihood of successful spawning in the Central Valley or of producing progeny from natural spawning that will survive.

Orchestrating Effective Science and Adaptive Management

Some of the actions outlined here should be undertaken soon, to keep options open, advance learning about what is most effective, and improve the system's resiliency. For instance, land use plans should reserve habitat areas, and flood managers should reinforce levees that protect critical infrastructure and urban areas. Other actions may take longer to implement or need further study, as they will need to respond to changing knowledge and changing conditions. For instance, additional analysis is needed to determine appropriate flow requirements and physical structures to manage flows; new responses will be needed when some islands flood or when new invasive species arrive.

The design and operation of a more sustainable reconciled landscape will require technical and scientific capabilities and coordination unprecedented since the development of the California Water Plan and construction of the CVP and the SWP. In contrast to those earlier efforts, which focused principally on achieving water-supply goals for human users of the system, creation of a reconciled Delta will also require an effective program of adaptive management. With adaptive management, environmental management is informed by, and adjusted to, the results of deliberate and integrated interdisciplinary modeling and experimentation (see text box on adaptive management).

Necessary data and analytical work toward this end include the following:

- **Creation of a suite of interacting models** (operations, hydrodynamics, water quality, food web, fish life history, economics, geomorphic conditions) that can support scientific adaptive management.
- **Development of three-dimensional hydrodynamic, sediment, and water-quality models.** Such modeling is needed urgently and must be broadly available to allow examination of long-term environmental performance of Delta solutions with sea-level rise, different island, levee, and barrier configurations, and different operations. Only three-dimension modeling can provide confidence in decisions involving the interaction of flow, landscape, tidal energy, water quality, and fish migration for a range of levee and island configurations (Gross, MacWilliams, and Kimmerer 2009).
- **Development of more detailed data inventories and modeling of in-Delta and near-Delta diversions, water use, and return flows, and methods to manage their effects on fish.** Adaptive management, modeling, and regulatory enforcement will require improvements in inventories, monitoring, and estimation of many aspects of the Delta and inflows.
- **Extensive field experiments on fish behavior and ecosystem responses.** Hypotheses about how ecosystem restoration might work need to be subjected to long-term experiments to improve understanding of the processes controlling species responses to restoration actions. In addition, pilot-scale experiments are needed to understand the consequences of planned restorations and unplanned island failure. Further studies of remaining remnants of natural landscapes and historical ecological analysis are needed to inform restoration goals, designs, and performance measures.

Adaptive management for the reconciled Delta

Ecosystems like that in the Delta can respond to management, but management efforts will produce surprises and disappointments. Managing with uncertainty presents a conundrum: a fixed strategy, easiest to set by law and practice, will not necessarily produce the desirable outcome. Achieving a particular desired outcome requires an adaptive strategy, with both the costs and the time needed being uncertain.

Adaptive management (AM) was developed in the 1970s and 1980s by C.S. Holling, Carl Walters, and others as a way to manage for desirable outcomes in the face of uncertainty (Hollings 1978). In AM, learning is incorporated into management through planned, iterative feedbacks involving computer modeling to integrate information and develop promising management actions, which are then tested in the field and refined. Management is designed in part to facilitate learning.

AM is a favored policy of federal stewardship agencies and the State of California. California's Natural Community Conservation Planning Act requires that NCCPs be managed adaptively. But adaptive management usually fails in practice (Walters 2007). Often policymakers do not understand it, thinking adaptive management means a policy of "decide now, reckon with consequences later." Other difficulties include a belief that science can answer difficult policy questions with certainty, a fear of uncertain outcomes with adaptive management as compared with greater (and perhaps false) assurances with negotiated "command and control" management, and the costs and institutional challenges of conducting the effective science needed to support AM.

Given the Delta's long history of intense resource conflict, the challenges to successful adaptive management are exceptional. Yet scholars of adaptive management provide some reasons for hope. The choice is stark: we must either make adaptive management work, or accept that future development and restoration work will likely produce undesirable outcomes.

- **Experimental island flooding and analysis of nutrient and biomass exchanges between habitats.** Such experiments can help assess the ecological interactions in these new habitats and consider how they can be managed to better support native species. Some experiments can be conducted by manipulating habitats on existing flooded islands. But it would also be valuable to experiment with flooding one or more islands that have characteristics—such as area, orientation and depth—more similar to those of the larger, deeply subsided Delta islands that have a high likelihood of flooding.
- **Modeling, analytical, and experimental work to predict effects of climate change.** The additional impacts of accelerating sea-level rise, warmer temperatures, more extreme storm events, extended droughts, and other likely effects of climate change need to be predicted to develop scenarios for management. These scenarios would have to be overlaid on results of the other studies recommended here.

The orchestration of such work is beyond the capabilities or culture of any current state or federal agency. Each state and federal agency, as well as many local agencies, non-governmental organizations, and universities, tends to have their own separately funded science programs, each of which investigates different questions with little common direction or synthesis for resolving the Delta's problems. Different state, federal, and local agencies also usually have their own independent "adaptive management" and restoration programs. In general, scientific and technical capabilities for the management of the Delta are poorly coordinated, although the Interagency Ecological Program provides some coordination, and the Delta Science Program (DSP)[16] is increasingly trying to provide leadership (e.g, by sponsoring the biennial Bay-Delta Science Conference).

A new scientific culture must be developed where diverse scientists and technical experts come together as a larger organized team to explore, develop, craft, test, and improve evolving solutions to the Delta's problems at strategic and tactical levels. Biological, ecological, hydrodynamic, water-quality, and operational expertise will need to be integrated effectively—a challenge for professional disciplines that are often segregated among agencies, with different cultures and missions and little experience working together on a common problem.

Delta Adaptive Management Alliance

The Delta will require a more effective institutional framework and adequate funding to support such an effort. One promising direction is to form a Delta Adaptive Management Alliance (Delta AMA) to unite the adaptive management efforts of a wide range of entities with an interest in improving environmental performance in the Delta. The DSP would coordinate and guide the AMA's activities. Most funding would go to structured research and development. Other agencies would implement these local and regional experiments, but the DSP would support these efforts and hold them to high standards of quality, including rapid publication of results and data. Such a structure would advance more effective adaptive management activities and provide a coherent scientific core for Delta issues, without preventing independent efforts by individual agencies and other entities.

Some operating principles for this alliance might include the following:

1. **Integration and synthesis of scientific and technical knowledge**. This would be the core mission of the Delta AMA.
2. **Inclusivity and coordination.** With the Delta Science Program at the helm, the Delta AMA would involve all state and federal agencies as well as universities and major stakeholders that wish to participate (e.g., local agencies and non-governmental organizations). Agencies or groups could decline to join, or could leave at any time, but it should be recognized that independent adaptive management programs are unlikely to work and could interfere with each other. Although coordination does not guarantee integration, ideally the AMA would be strong enough to integrate the most important adaptive management actions.
3. **Pooling of resources.** Resource pooling is one key to integration. Because there are likely to be large untapped economies of scale, resource pooling would also allow adaptive management dollars to be spent more effectively. (Currently, at least four 3-D Delta hydrodynamic models are being developed independently.) The AMA would need to garner enough financial resources from its members to induce agencies to integrate their adaptive management efforts. Voting on major decisions might be weighted by agency contributions.
4. **Diverse incentives for affected parties.** The shared goals of the AMA should help to overcome some stakeholder resistance to adaptive experimentation. To keep down costs, regulatory relief should be explored as an alternative to financial compensation to those whose land or water resources are adversely affected by experimentation.

[16] Prior to the Delta Reform Act of 2009, this entity was known as the CALFED Science Program. The Delta Science Program reports to the Delta Stewardship Council, also created under that law.

5. **Scientific leadership.** The Delta AMA would appoint a Lead Scientist for a minimum of three years (or up to seven years to improve scientific constancy).
6. **Staffing through reassignment.** Member agencies would assign individual technical and scientific staff to the common adaptive management organization, where they would be co-located. Professional staff could be released at any time by the Lead Scientist.[17]
7. **Advisory role for technical experts.** A diverse group of technical experts would participate in ad hoc advisory groups. The purpose of these groups would be to gain technical insights and review from experts who can see the big picture. Although some of these experts might be funded by stakeholder groups, this would not be a forum for agency and stakeholder representatives to air institutional positions. Rather, participants would be asked to bring their professional expertise and independent judgment to the advisory group.
8. **Independent scientific review.** An Independent Science Board would meet twice yearly to review the overall program at a high level. The DSP Independent Science Board could fulfill this role.

Adaptive management activities of the AMA would include the following:

1. **Structured R&D program.** Most funding would go toward this coherent scientific effort, where data and model development and field experiments are designed to inform each other in a systematic way. Most of this work would be done by other entities, but subject to external review.
2. **Unstructured R&D program.** This basic science component would allow continued investigator-initiated exploration of new topics. It would function largely as the current Delta Science Program–funded research (DSP provides grants to researchers for their own proposals, selected through a competitive process). This is important for the long run, and would be funded at roughly current levels.
3. **Individual agency research programs**. Considerable high-quality work is conducted within agencies, but it is not sufficiently distributed or integrated into the thinking of the broader community. By the same token, the direction of such research could often be improved by considering broader efforts and concerns. The AMA would provide a forum for coordination and sharing of this work, which would continue to be funded by individual agencies.
4. **Data collection program.** The Interagency Ecological Program and others have made some progress in this area, but additional efforts to develop databases useful for the broader community would be helpful. The AMA roles would mostly be to set standards and coordinate efforts.
5. **Knowledge integration and acquisition.** A small AMA team would focus on technical knowledge synthesis, through modeling and data analysis, mostly in coordination with staff in other agencies and institutions. Developing a common data and modeling development effort across agencies is essential and would provide substantial economies of scale. Developing standards for open data, study efforts, and documentation would also go a long way to increasing the accessibility, utility, and quality of Delta science overall.
6. **Knowledge synthesis**. Panels of staff and external experts would produce policy-relevant reports and presentations on what the scientific and technical community has learned and expects to learn, drawing implications for policy and management decisions. Healey, Dettinger, and Norgaard's *The State of Bay-Delta Science* (2008) is a good example.
7. **Regulatory coordination.** Adaptive management experiments will face major state and federal regulatory challenges. The AMA would take the lead in coordinating these efforts. Regulatory agencies that are members of the AMA would commit to working toward more streamlined permitting and approvals.

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[17] Lund, Hanak, and Gray (2011) provide some rough estimates on staffing needs.

8. **Stakeholder coordination**. Stakeholders will have a keen interest in the adaptive management program, and it will be essential to keep them engaged constructively.
9. **Communications.** Effective internal and external communications of the AMA's and the broader community's scientific efforts will be needed.

Delta AMA products would include: (1) a biennial report on state of knowledge and plans for improvement, (2) an annual report of activities, finance, and state of fishes, levees, and water supply reliability, (3) individual reports on specific efforts and experiments (done to quality control and documentation standards), (4) a common model and data development plan for AMA efforts and agencies, and (5) biennial assessment of funded and coordinated activities.

Legal and Policy Implications

The preceding discussion proposes significant changes in ecosystem management and science policy to implement a reconciliation strategy in the Delta. Here, we comment on two other policy-related aspects of reconciliation: How compatible is this strategy with existing environmental laws? And what types of policies might be necessary to address potential negative effects on human users of Delta lands and waters?

Reconciliation Is Compatible with Environmental Laws

The reconciled Delta described in this report is compatible with the various environmental laws that govern the ecosystem. This is true both for the laws that provide for the flexible administration of water rights and water quality and for those that impose more categorical protections for fish, aquatic habitat, and other environmental uses of the waters of the estuary.

For example, the federal CWA and the California Porter-Cologne Act direct the State Water Resources Control Board (SWRCB) to establish water quality standards that provide reasonable protection for all beneficial water uses in the Delta ecosystem. These statutes vest the Board with authority to accommodate the often-competing interests of agricultural and urban water supplies (including upstream, in-Delta, and export uses), fish and wildlife, recreation, navigation, and ecosystem services.

The changes we recommend would alter the existing physical structure of the Delta and the administration of the water supply systems that affect flows of water within and through the estuary. The SWRCB has authority to find that such changes are consistent with water quality standards for the Delta and the state constitution's reasonable use doctrine, and to approve such changes within its water rights jurisdiction. The flow and water quality standards for a reconciled Delta may strike a different balance between native and non-native species or designate some areas of the Delta for specialized uses (e.g., consumptive water supply, pelagic fish habitat, migratory corridors, shallows, etc.). However, these types of changes are within the board's broad and flexible authority "to attain the highest water quality which is reasonable, considering all demands being made and to be made on those waters and the total values involved, beneficial and detrimental, economic and social, tangible and intangible." (Water Code § 13000; *U.S. v. SWRCB* 1986). Moreover, the SWRCB has the power to adjust the water rights of users who divert water from or upstream of the Delta as needed to achieve the water quality standards, to ensure the reasonable use of water, and to protect the public trust (*U.S. v. SWRCB* 1986).

A similar analysis would apply to the Delta Stewardship Council in crafting a Delta Plan under the directives of the Sacramento–San Joaquin Delta Reform Act of 2009. The statute requires the Council to accomplish many of the objectives recommended here, including maintenance of "viable populations of native resident and migratory species," creation of "functional corridors for migratory species," and restoration of "diverse and biologically appropriate habitats and ecosystem." It also directs the Council to promote California's economic vitality by "meeting the needs for reasonable and beneficial uses of water," and "improving water quality to protect human health and the environment." This, too, is consistent with the reforms we recommend.

Other statutes, such as the federal and state ESAs, are narrower and less flexible in their goals. These laws prohibit or place conditions on federal, state, and private actions that may jeopardize the continued existence of listed species, including in some cases alteration of the critical habitat of the species. They also prohibit the "taking" of any member of a protected species unless the taking is authorized by a biological opinion or by a permit that is consistent with an approved program to protect the species' habitat (Salzman and Thompson 2010).[18]

All Delta species listed for protection under the ESAs are native species. As our reconciled Delta proposal calls for protecting and improving conditions for all native species, there should be no significant conflicts with the categorical directives of these statutes. Although a reconciled Delta may diminish the habitat or suitability of the waters for some non-native or invasive species, none of these alien species are listed under the federal or state ESAs. Moreover, if it is necessary to suppress alien species that compete with or degrade the habitat of native species, losses of these aliens would further the purposes of the ESAs.

Although a reconciled Delta would be generally consistent with these most important laws that govern the ecosystem, some recommendations present more specific legal issues. For example, it will be necessary to evaluate the proposals for consistency with laws governing federal and state flood policies. Migration corridors for salmon and steelhead and removal and relocation of levees would also require permits from the Army Corps of Engineers under sections 404 and 408 of the CWA. Changes in the volume or timing of water diverted to or released from upstream storage, as well as changes in the quantity and timing of pumping from the Delta, may require adjustments in water right permits. Changes in upstream releases require the approval of the California Department of Fish and Game under Fish and Game Code § 5937, which requires that fish below dams be maintained in good condition.[19] These changes also might require coordination with the Federal Energy Regulatory Commission, which regulates licensing of hydropower facilities. Intentionally flooded islands—called for here as part of an experimental adaptive management strategy—might change water quality to the detriment of some existing beneficial uses, and therefore necessitate a waiver of the U.S. Environmental Protection Agency's anti-degradation policy, adopted pursuant to section 303(d) of the CWA (Suddeth 2011). Finally, new limitations on the discharge of pollutants from point and nonpoint sources upstream of and within the Delta would require new or amended National Pollution Discharge Elimination System (NPDES) permits and waste discharge requirements issued by the Central Valley and San Francisco Regional Water Quality Control Boards.

At present, each federal and state agency involved in environmental oversight has its own permitting and regulatory powers. It would be desirable for these agencies to pool information and act in a cohesive and integrated way, with the goal of "one-stop permitting" or at least coordinated permitting. Such coordination could enhance the effectiveness of environmental regulations, while lessening the costs to water and land users, who typically must seek multiple state and federal environmental permits to undertake any new investments in the region.[20]

When Is Mitigation Appropriate for Human Land and Water Users?

In a reconciled Delta, humans will continue to use most land and water within the Delta watershed. But many of the changes discussed here could harm some individuals or communities. Some losses will result from external forces, such as earthquakes and sea-level rise, while others will result from management decisions

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[18] The federal ESA identifies these programs as habitat conservation plans or "HCPs," while the California ESA calls them natural community conservation plans or "NCCPs."

[19] See Hanak et al. 2011, Chapter 5 and Moyle and Gray 2011 for a discussion of this law.

[20] For instance, a program involving dredging in the north Delta potentially required 16 different permits from 11 different agencies (California Department of Water Resources 1988). According to the plaintiffs in a lawsuit related to this project, the number of required permits was even higher (22).

designed to improve conditions for native species. For instance, permanent island flooding—a result of external forces —will reduce revenues and jobs on the islands themselves (primarily farming) and cause wider economic losses within the Delta owing to economic multiplier effects (Medellín-Azuara et al. 2012). Conversion of farmland to habitat—a result of management decisions—can have similar economic effects. Likewise, management decisions that increase or alter flows to support estuarine function may reduce supplies or alter the quality of water available for human water users. Stricter controls on pollutant discharges can have benefits for the environment and some water users, but also costs for the regulated parties.

Only some of these changes require mitigation for economic losses. In particular, compensation is required in exchange for lands acquired for habitat programs. Similarly, any intentional breaches in Delta islands would require compensation of landowners, either by agreement or by exercise of state or federal eminent domain authority (Suddeth 2011). In contrast, unless the changes are so severe that they result in a taking of water right or breach of water service contract, regulatory adjustments in water quality and flow standards do not require compensation (Gray 2002a & 2002b). Nor is the government liable to compensate landowners whose property is damaged by natural forces, such as the flooding of Delta islands and shore lands by unintentional levee breaches or sea-level rise.[21]

Even when mitigation is not legally required, it may be sound public policy to provide temporary or transitional support for disadvantaged groups that suffer disproportionately from changes in Delta conditions. Such programs could include tax and conservation easement incentives to retire agricultural lands and transitional compensation to farmworkers or others whose employment opportunities are diminished by sustained decreases in irrigation water service or agricultural land retirement.

The mechanisms for addressing such effects on the wider community are less well-established than land purchases or easement payments to landowners. But some potential models are found in California's water market as well as a large public land acquisition program in the Pacific Northwest (Medellín-Azuara et al. 2012). In two long-term agricultural-to-urban transfers of water in Southern California involving land fallowing, multimillion-dollar funds were set aside to help address the needs of the wider community. For the transfer from the Imperial Irrigation District to the San Diego County Water Authority, funds are awarded to applicants who make a case that their business activity has been harmed by the fallowing. For the transfer from the Palo Verde Irrigation District to the Metropolitan Water District of Southern California, funds are used to support local economic development and workforce training, rather than for direct compensation. The Northwest Forest Plan used a similar model, with a fund to provide training and assistance for workers affected by the protection of about 20 million acres of federal land from logging as part of an ecosystem protection effort for the endangered spotted owl and other species. Recent negotiations by Yolo County also provide a model for how local governments might be made whole when land changes hands. When land is transferred to public agencies, it is generally no longer liable for property taxes. Yolo has obtained agreements to maintain revenue streams from lands in new habitat-mitigation banks, such as those established on some lands in the northern Delta. The county negotiated a similar deal with the Sacramento Area Flood Control Agency (SAFCA), which purchased conservation easements in an area of the county to help reduce future flood risks in some urbanized lands within the SAFCA service area.

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[21] The exception is damage incurred from failure of levees that are part of the federally-authorized flood control project for the Central Valley. The 2003 Paterno decision held the state liable for such failures. Roughly a third of the Delta's levees are "project" levees—principally those protecting areas near Stockton and Lathrop in the eastern and southern Delta and along the Sacramento River corridor in the northern Delta (see Lund et al. 2007, Figure 2.2).

Conclusion

The conflicts over ecosystem, land, and water resource management in the Sacramento–San Joaquin Delta are urgent and worsening. Given the immense changes the region has experienced since statehood, it will be impossible to restore the Delta to its pre-development conditions, or even to the way it was a few decades ago. Ongoing and future changes associated with sea-level rise, land subsidence, invasive species, climate change, and earthquakes also make it impossible to preserve the Delta in its current state. Plans for the Delta must therefore prepare for change and adaptation.

Ecosystem reconciliation is a promising approach for addressing the problems of native species declines in the Delta. Reconciliation implies a need to accept diverse human and environmental uses of the Delta. A reconciliation strategy recognizes that some major human features of the Delta landscape will largely remain intact, even though they hinder recovery of native species. Thus, levees will continue to protect urban areas, infrastructure, and farmland from flooding, even though they alter flow patterns and habitat access. The deep-water ship channels will continue to exist, despite their adverse effects on flows and water quality delivery and the frequently unfavorable habitat they create. Agricultural and urban water users will continue to divert water from the system, and wastewater treatment plants will continue to discharge into it. In a reconciled Delta, efforts are made to reduce adverse effects on the ecosystem from such human activities, but many of these effects will not be eliminated. This approach will not eliminate conflict, but it provides a constructive framework for seeking improvements.

Specialization of different parts of the Delta to meet different objectives seems both promising and practical. Existing elevations largely determine the suitability of different areas for different types of habitat. Deeply subsided lands within the inner Delta are unsuitable for rebuilding tidal marsh and seasonal floodplain habitat that native species need over different stages of their lives. Access to freshwater inflows, tidal energy, and other factors are also important.

The vision outlined here calls for an arc of habitats from Suisun Marsh to the Yolo Bypass to support native estuarine species (particularly delta smelt, splittail, and salmon). Some deeply subsided islands in the central Delta are likely to permanently flood, increasing aquatic habitat favorable to freshwater lake species such as largemouth bass. Riparian areas fed by eastside streams and the San Joaquin River would be better connected with floodplains to support resident fish species and migrating salmon. Gates, barriers, and levees would help direct flows and support fish migrations, while keeping native fish out of unfavorable areas. Water system operations, including reservoir releases and diversions upstream, within, and below the Delta would be fine-tuned to support these specialized ecosystem objectives. A tunnel or canal to divert water exports upstream of the Delta for transport to the south Delta pumps would provide more flexibility to support ecosystem and water supply goals simultaneously. Despite these changes, much of the Delta's structure, such as the levees protecting urban areas and the deep-water ship channels, would remain in place, and agriculture would remain an important economic activity within the inner Delta (Medellín-Azuara et al. 2012).

Managing a reconciled Delta will require a seriousness of purpose not seen in state and federal water agencies since the construction of the Central Valley Project and the State Water Project in the mid 20th century. Major technical and scientific efforts, combined with effective and stable institutions and funding, will need to develop and continually adapt effective solutions as time and events unfold.

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