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Costs of Ecosystem Management Actions for the Sacramento–San Joaquin Delta

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Summary

Reversing declines in the populations of native fish in the Sacramento–San Joaquin Delta is a major water policy challenge for California. In choosing a portfolio of management actions to improve conditions for these fish, two considerations are key: the actions' ecological potential to support these species and the costs to those using the Delta's lands and waters. This report is a first attempt to sort a large suite of potential actions by their economic and financial costs. Estimates are drawn from the literature, discussions with program managers, and modeling results. These costs can include additional operational expenses, new investments in infrastructure or facilities, and losses in value added or net returns to management when economic activity declines because of management changes (e.g., reduced diversions or reduced use of agricultural chemicals). To facilitate comparisons, all costs are presented in annualized terms. We found a wide range of costs among more than 30 ecosystem management actions, from under $1 million per year to over $700 million. A comprehensive management package will likely cost at least several hundred million dollars per year on an ongoing basis. In many cases, there has been an expectation that individual groups would bear the costs directly. Even where taxpayer funds are expected to contribute, fiscal and social realities will require implementing ecosystem management cost-effectively.

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) *Integrated Management of Delta Stressors: Institutional and Legal Options* (Gray et al. 2013) presents our proposals for institutional reform of science, management, and regulation; (3) *Where the Wild Things Aren't: Making the Delta a Better Place for Native Species* (Moyle et al. 2012) describes a realistic long-term vision for achieving a healthier ecosystem; and (4) *Scientist and Stakeholder Views on the Delta Ecosystem* (Hanak et al. 2013) presents the results of surveys of scientific experts and engaged stakeholders and policymakers on Delta stressors and the management actions described here. All of these reports are available on PPIC's website at www.ppic.org.

Contents

Figures

Tables

Abbreviations

af	acre-foot
BDCP	Bay Delta Conservation Plan
CALTRANS	California Department of Transportation
CCWD	Contra Costa Water District
cfs	cubic feet per second
CVP	Central Valley Project
CVRWQCB	Central Valley Regional Water Quality Control Board
DBW	Department of Boating and Waterways
DFG	Department of Fish and Game (former name of DFW)
DFW	Department of Fish and Wildlife
DPR	Department of Pesticide Regulation
DWR	Department of Water Resources
ESA	Endangered Species Act
GDP	gross domestic product
maf	millions of acre-feet
NMFS	National Marine Fisheries Service
NPDES	National Pollution Discharge Elimination System
RO	reverse osmosis
SRCSD	Sacramento Regional County Sanitation District
SWAP	Statewide Agricultural Production model
SWP	State Water Project
SWRCB	State Water Resources Control Board
taf	thousands of acre-feet
USBR	U.S. Bureau of Reclamation

Introduction

Management of the Sacramento–San Joaquin Delta's aquatic ecosystem is the most vexing water policy challenge facing California today. The Delta is a network of mostly manmade islands and channels at the confluence of the Sacramento and San Joaquin Rivers, and it serves as both a major source of the state's water supply and a valued ecological resource. Over the past several decades, sharp declines in several types of native fish species have heightened conflicts over the management of water and land resources in this region and the ecologically related upstream areas.[1] Eleven native fish species are now listed as endangered, as threatened, or as species of concern under the federal and state Endangered Species Acts (ESA).

There is now broad scientific recognition that a wide range of stressors—most resulting from human management of the water and land resources of the Delta and the greater watershed—are jointly responsible for the undesirable changes to the Delta ecosystem (National Research Council 2012; Delta Independent Science Board 2011). This recognition is reflected in the two most recent, high-profile efforts at coordinated management approaches: the Delta Plan and the Bay Delta Conservation Plan (BDCP). The Delta Plan is the state's foundational long-term (100-year) plan for meeting the "co-equal goals" of water supply reliability and ecosystem health established by the Delta Reform Act of 2009 (Cal. Water Code § 85054); it is scheduled to be adopted in the spring of 2013.[2] The BDCP, under development since 2006 and scheduled for public review in 2013, is a habitat conservation plan for the Delta that would simultaneously provide broader environmental protections for the Delta's endangered aquatic and terrestrial species and a more reliable framework for continued water exports under the terms of both federal and state ESAs.[3] Although large—potentially involving multibillion dollar investments in Delta habitat restoration and new water conveyance infrastructure—BDCP is more narrowly focused. If deemed sufficiently protective of native species, BDCP will be incorporated into the Delta Plan, as will other plans related to Delta management (e.g., water quality and flows, flood protection) and the conduct of Delta science.[4]

Identifying a comprehensive strategy for improving conditions for the Delta's native aquatic species will require balancing both the potential ecological effectiveness of management actions and the costs of these actions. Ideal actions would have the highest ecological potential and the lowest costs to society. In practice, significant tradeoffs between these goals are likely, because some high-potential actions are also likely to be costly.

This report provides the first broad assessment of the costs of a large suite of actions that might improve conditions for native fish species in the Delta, including those under consideration in BDCP, the broader Delta Plan, and other ongoing and related processes. It serves to complement the scientific expert assessments of the potential ecological effectiveness of such actions and the identification of priority packages of actions by both scientists and stakeholders in two companion reports: *Stress Relief: Prescriptions for a Healthier Delta Ecosystem* (Hanak et al. 2013a) and *Scientific and Stakeholder Views on the Delta Ecosystem* (Hanak et al. 2013b). We examine the same set of actions as these reports, and we draw on

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[1] We use the term "Delta ecosystem" when referring to the statutory Delta and Suisun Marsh on its western edge (Cal. Water Code § 85058) and the term "Delta watershed" or "greater watershed" when referring to the Sacramento River and San Joaquin River hydrologic regions that drain into the Delta (including the Mokelumne and Cosumnes Rivers) (Cal. Water Code § 85060).

[2] When discussing this plan, we refer to the last staff draft, issued in November 2012 (Delta Stewardship Council 2012).

[3] When discussing this program, we refer to materials that were made public in 2012 before release of the formal public review draft (Bay Delta Conservation Plan 2012).

[4] Technically, BDCP must meet the conservation standards of the state's Natural Communities Conservation Planning Act, which provide for recovery of listed species, and it must otherwise be deemed consistent with the Delta Plan (Gray et al. 2013). For an overview of other related planning processes, see Mount (2011) and www.aquafornia.com/wp-content/uploads/2012/07/DeltaOrganizationChart1.pdf.

existing literature, modeling results, and discussions with knowledgeable individuals to identify likely ranges of costs. In some cases, the actions themselves are not well-defined in any current policy proposals, so it has been necessary to make rough assumptions of what the action might entail, as well as the potential costs. Although we hope the numbers presented here may be useful for a coarse sorting of actions, additional work is needed to provide more precise definitions of actions and more accurate cost estimates.

The report is organized as follows. The next section presents an overview of management actions and describes the approach we used for estimating costs, including caveats regarding their interpretation. The third section presents estimates of the costs of individual actions, and a concluding section summarizes key findings.

An Overview of Management Actions and Cost-Estimation Methods

Table 1 lists the 32 management actions we will examine. This is the same list of actions we asked scientists to evaluate for their potential to improve the Delta ecosystem's ability to support native fishes in a summer 2012 survey (Hanak et al. 2013a, 2013b). The list includes interventions addressing each of five broad types of ecosystem stress: discharges, direct fish management, flow regime, invasive species, and physical habitat. (For a description of this classification, see the companion report, *Aquatic Ecosystem Stressors in the Sacramento–San Joaquin Delta* [Mount et al. 2012]).

Actions within each stressor group are sorted by level of implementation experience within the Delta watershed—a guide to the types of data we were able to obtain on likely costs. Over half of these actions (denoted as "under way") are already employed to some extent within the Delta watershed, with additional implementation planned or being considered.[5] Other measures have yet to be tried here. Two measures—tidal marsh restoration (#29) and farm fertilizer discharge control (#5)—are planned for near-term implementation ("planned"). Several others are being considered based on modeling or experience outside the basin ("considered"). For example, the BDCP negotiators are studying construction of a canal or tunnel to divert exports around or underneath the Delta (#21). Finally, some actions are still at the conceptual stage ("conceptual") and not yet sufficiently developed for active consideration. These ideas include ways to control invasive clams (which compete with native species for food) (#24) and to increase sediment available to the Delta (which could help support tidal marsh restoration) (#32).

[5] The Sacramento Regional County Sanitation District—the Delta's main urban point source of ammonium—has been ordered to upgrade its treatment facilities by 2022. Efforts also are under way to reduce farm pesticide discharges, to improve flow regimes upstream of the Delta, and to expand seasonal floodplain habitat in the Yolo Bypass. The National Marine Fisheries Service (NMFS) has proposed removing two dams on the Yuba River to improve salmon access to upstream habitat. (Some smaller dams have already been removed in upstream tributaries, such as Butte Creek, Battle Creek, and Clear Creek.)

TABLE 1
Many actions might help improve conditions for the Delta's native fishes

	Action	Implementation stage [a]	Annualized costs [b]
Discharges	1. Reduce urban nonpoint discharges (e.g., stormwater, landscaping runoff)	Under way	$–$$
	2. Reduce farm pesticide discharges	Under way	$$–$$$
	3. Reduce toxic substance discharges (e.g., emerging contaminants)	Under way	$$–$$$
	4. Reduce urban point discharges (e.g., wastewater treatment plants, industry)	Under way	$$–$$$
	5. Reduce farm fertilizer discharges	Planned	$$$
	6. Dilute pollutant loads with increased freshwater flows	Considered	$$–$$$
Direct fish management	7. Truck juvenile salmonids around the Delta	Under way	$
	8. Increase enforcement to prevent poaching	Under way	$
	9. Increase screening of water diversions	Under way	$–$$
	10. Develop new conservation hatcheries to support native fish (e.g., delta smelt hatchery)	Under way	$$
	11. Reduce harvest of anadromous fish (salmon, steelhead, sturgeon)	Under way	$$
	12. Trap and truck fish around dams	Considered	$
	13. Allow unrestricted fishing on nonnative predatory fish (e.g., striped bass, largemouth bass)	Considered	$$
	14. Manage hatcheries to separate hatchery fish from wild populations (e.g., change hatchery locations, mark hatchery fish)	Considered	$$
Flow regime	15. Add gated structures within the Delta to improve fish passage	Under way	$–$$
	16. Reduce entrainment at export pumps	Under way	$$
	17. Reduce Delta exports	Under way	$$–$$$
	18. Increase net Delta outflows	Under way	$$–$$$
	19. Improve flow regime upstream of the Delta	Under way	$$–$$$
	20. Pattern Delta flow variability to support native species	Considered	$$–$$$
	21. Divert Delta exports through a canal or tunnel	Considered	$$$
Invasive species	22. Directly control invasive aquatic vegetation	Under way	$–$$
	23. Increase actions to prevent new invasions (e.g., ballast water, trailered boats, aquarium trade)	Under way	$$
	24. Directly control invasive clams	Conceptual	$–$$
	25. Increase salinity variability in the Delta	Conceptual	$$$
Physical habitat	26. Expand seasonal floodplains	Under way	$–$$
	27. Improve or increase upstream spawning and rearing habitat	Under way	$$
	28. Remove selected dams	Under way	$$–$$$
	29. Restore tidal marsh and shallow water habitat (e.g., Liberty Island, Suisun Marsh)	Planned	$$
	30. Improve in-Delta channel margin habitat (e.g., setback levees)	Considered	$$
	31. Increase deep-water habitat (e.g., Franks Tract, Mildred Island)	Conceptual	$$
	32. Increase sediment loads flowing into Delta	Conceptual	?

NOTES: [a] "Under way" denotes actions that are currently being implemented in the Delta watershed to some extent; "planned" denotes actions not yet implemented but planned for near-term implementation; "considered" denotes actions being considered based on modeling or experience outside the basin; "conceptual" denotes actions still at the conceptual stage and not likely to be implemented in the near term.

[b] $, < $10 million; $$, $10 million to $99 million; $$$, $100 million to $700 million. Investment costs are annualized at a 5 percent rate for perpetuity (so, a $1 billion investment costs $50 million per year). Costs do not include economic spillover (multiplier) effects, e.g., additional revenue losses in other sectors from reductions in agricultural output or increased revenues from new investments.

Table 1 also summarizes our rough estimates of the annual costs to implement each action. For some actions, the cost estimates reflect expenditures required for implementation—e.g., hiring more game wardens to reduce poaching (#8) or investing in a new wastewater treatment plant to reduce urban point discharges (#4). However, for many actions the cost will instead reflect losses to water and land users whose activities would be constrained by new measures. This is true of most flow-related measures (which imply some reductions in human water diversions), some fish management measures (which imply reduced commercial and recreational fishing), and some others. We aim to present a measure of the direct losses in economic value from these actions. This is typically less than the loss in revenues. Variations in data sources have meant that the specific measures used for estimation also vary somewhat across actions. One measure—"value added"—includes the returns to labor, management, and assets. It is typically equivalent to the value of sales of a commodity (or "gross revenue") minus the production costs of nonlabor inputs, and it is the measure most closely corresponding to state and national measures of gross domestic product (GDP). An alternative, smaller measure sometimes used instead for agricultural calculations is "net farm revenues"—or the returns to land and management. This is equivalent to value added minus nonmanagement labor inputs. Estimates for flow-related actions using the CALVIN model of water management (#16—#18 and #25) include this measure for agricultural losses as well as estimates of the economic costs of shortages in the urban sector.

We account only for the direct economic costs of actions, not the indirect economic costs or benefits—often known as spillover or multiplier effects. For instance, the direct costs of reducing exports would likely include lost farm revenues, and indirect costs would include the resulting loss of other economic activity—lower purchases of agricultural inputs, lower volumes processed and handled after production, and potentially lower overall spending in the regional economy. Likewise, the direct costs of habitat restoration would include land acquisition and investments (in addition to operation and maintenance costs of the site) to convert the land to suitable habitat. Indirect costs would include spillover effects on the local economy from a reduction in agricultural production, and indirect benefits would include job creation from the habitat investments, ongoing maintenance of these lands, and potential increases in eco-tourism. Such spillover effects typically lie in the range of 1.1 to 3.5—and 1.9 on average across all sectors—meaning that the overall economic effect may be 1.1 to 3.5 times larger than the direct effect.[6]

Where possible, we distinguish between estimates of one-time investments and ongoing operational costs. To facilitate comparisons across actions, we present investments in annualized terms, using a 5 percent discount rate in perpetuity. (This is equivalent to assuming that the annual cost of an investment is one-twentieth of its initial capital cost).

Because many of the actions could be undertaken to varying degrees, we also seek to provide ranges of costs when the unit costs of an action are not constant. As an example, the per-acre-foot costs to the economy of very small reductions in water exports from the Delta are likely to be much lower than the costs of very large reductions, because not all water use has equal economic value. Likewise, the per-acre costs to the economy of converting agricultural land to habitat may increase as more land is taken out of production

For many actions described here, some sectors or regions would likely bear the brunt of the costs unless programs were established to cover them with other funds (e.g., state or federal tax dollars). Figure 1 presents an overview of the areas within the state that could be directly affected. Many actions would directly affect residents and businesses within the greater Delta watershed—the Sacramento River and the San Joaquin River hydrologic regions. (As of 2005, the Sacramento River region had roughly 2.9 million inhabitants and 1.9 million acres in irrigated agricultural production, and the San Joaquin River hydrologic region had roughly 2 million inhabitants and 2 million areas in irrigated agricultural production.)[7] Because these areas drain into the Delta, they are the relevant areas for actions to

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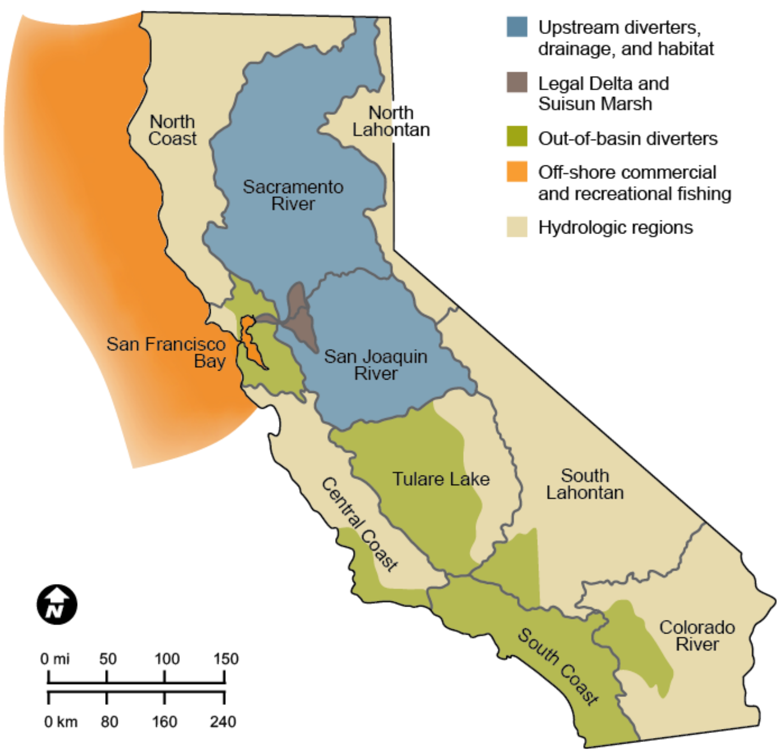
[6] These are value-added multipliers for 2010 for counties overlapping with the greater Delta watershed (Alameda, Colusa, Contra Costa, Glenn, Madera, Merced, Sacramento, San Joaquin, Shasta, Solano, Stanislaus, Sutter, Tehama, Yolo, and Yuba), obtained from IMPLAN (IMpact analysis for PLANning), a widely used model to calculate the regional economic effects of policy changes). Such calculations generally overestimate indirect costs or benefits, because they assume that the economy has no capacity to adjust to the changes by reallocating resources.

[7] Information on population is from the regional reports in the California Water Plan Update 2009 (California Department of Water Resources 2009). Information on irrigated acreage is from the University of California, Davis, Statewide Agricultural Production (SWAP) model (http://swap.ucdavis.edu)—those estimates are the same as the Water Plan Update for the San Joaquin River hydrologic region and slightly lower for the Sacramento River region, corresponding roughly to the 1.85 million acres on the valley floor, with an additional 0.25 million acres in upland areas largely devoted to irrigated pasture.

control polluted discharges (#1–#6). Watershed inhabitants also divert significant volumes of water both upstream and within the Delta for municipal and agricultural uses (Lund et al. 2010), and they would consequently be directly affected by many flow-related actions (#18, #19, #20, and potentially also #15) as well as fish management actions related to water diversions (#9) and all improvements of in-Delta and upstream habitat (#26–#32). Upstream diverters within the San Francisco Bay hydrologic region would be affected in similar ways for flow-related actions, and those near the Delta's western edge (Contra Costa and Solano Counties) would be affected in similar ways for discharges.[8] In addition, nearly 29 million residents in several other regions (the southern San Joaquin Valley, parts of the Bay Area, and Southern California), and more than 3 million acres of irrigated farmland, would be affected by flow-related actions directed toward Delta exports (#16, #17, #20, #21, and potentially also #15 and #19).[9] Fishery-related actions (#7–#14) could directly affect the recreational fishing sector within the Delta as well as the coastal commercial and recreational salmon fishery.

Because some actions overlap, the total costs of implementing a package might be lower than the sum of the components. This is particularly true for actions involving flow manipulation (#6, #15–#21, and #25).

FIGURE 1
Many parts of the state could be directly affected by ecosystem management actions



NOTES: Out-of-basin diverters include those receiving Delta exports as well as parts of the San Francisco Bay region receiving water from the Mokelumne and Tuolumne Rivers. Some water users in the San Joaquin River hydrologic region also receive Delta exports.

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[8] This includes customers of the East Bay Municipal Utilities District (Alameda and Contra Costa Counties) and retail and wholesale customers of the San Francisco Public Utilities Commission (San Francisco, San Mateo, and Alameda Counties). Both of these systems divert water upstream of the Delta (from the Mokelumne and Tuolumne Rivers, respectively) and convey it through aqueducts to the Bay Area.
[9] The Tulare Lake basin hydrologic region includes large portions of Fresno, Kings, Tulare, and Kern Counties. Southern California customers using Delta exports include most residents and businesses within the South Coast hydrologic region (Ventura, Los Angeles, Orange, San Diego Counties) as well as many residents in San Bernardino and Riverside Counties (South Lahontan and Colorado River hydrologic regions) and some in San Luis Obispo and Santa Barbara Counties. Within the San Francisco Bay Area, most Santa Clara County residents and some within Alameda County rely on Delta exports.

Cost Estimates for Individual Actions

Here we present our analysis of the cost of the 32 actions listed in Table 1, organized by the five stressor categories. For easy cross-referencing with Table 1, we summarize the implementation stage and cost range for each action as it appears there.

Discharges

The first six actions address the stress on the Delta ecosystem caused by land and water use activities that directly alter water quality by discharging various contaminants that degrade habitat, disrupt food webs, or cause direct harm to populations of native species (point and nonpoint sources of conventional pollutants, nutrients, toxics, endocrine disruptors, etc.).

Action #1: Reduce urban nonpoint discharges (under way, $–$$)

Although nonpoint source pollution from urban runoff has become subject to progressively stricter regulation since the 1990s, it remains a significant source of water quality impairment in much of California.[10] This runoff can include pesticides and fertilizers from urban applications, often in higher concentrations than farm runoff. (Urban users are more likely to apply these products on outdoor hard surfaces like building walls, driveways, and walkways, from which rainwater or sprinkler overspray can readily wash chemicals into storm drains.) For instance, the Central Valley Regional Water Quality Control Board (CVRWQCB) estimates that the urban sector accounts for half or more of the discharges of pyrethroids (a class of pesticides harmful to aquatic life) into the Delta.[11] Other harmful urban runoff includes sediment from construction sites, pet waste, and trash. Responsibility for reducing urban runoff lies with municipal and county governments and the California Department of Transportation (CALTRANS), which are required to have National Pollution Discharge Elimination System (NPDES) permits. These permits typically require the use of best management practices to reduce runoff and rarely have quantitative reduction goals. However, this may be changing following lawsuits and other pressures leading to stricter enforcement.

Cost estimates for reducing urban runoff vary widely, depending both on the extent and the nature of efforts assumed. At a very general level, the U.S. Environmental Protection Agency conducts spending needs assessments every four years. Its most recent assessment, in 2008, put annual capital costs for managing urban nonpoint source pollution in California at $3.9 billion for a 20-year period (or $194 million per year in 2008 dollars, excluding interest). These estimates covered such actions as improved conveyance infrastructure, treatment systems, green infrastructure (e.g., more onsite retention of stormwater), and general stormwater management (U.S. Environmental Protection Agency 2009). The estimates exclude operating costs, and it is likely that actual spending is lower given the difficulties that many local agencies face in raising funds for runoff management, which is subject to direct voter approval under Proposition 218 (Hanak et al. 2011).

Much higher costs have been estimated for specific aspects of runoff management. For instance, CALTRANS estimated a cost of $5 billion to retrofit state highways to meet new runoff regulations established in a legal

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[10] Although urban runoff is often referred to as a nonpoint source because it does not come from wastewater treatment plants or industrial discharge points, it is technically a "point source" under the Clean Water Act because it comes from storm drain pipes.
[11] See Foe (2011) and also Weston and Lydy (2010).

settlement (Hanak and Barbour 2005). Gordon et al. (2002) estimated that full compliance with a proposed "zero trash" limit in Los Angeles County could cost as much as $102 billion, assuming that treatment was installed at individual storm drains. (Although costs might be much lower with some alternative control mechanisms, this example also shows how very strict levels of regulations can induce very high costs; it takes the "zero trash" limit at face value).

For the Delta's aquatic species, one recent example shows that the costs can be relatively limited with approaches focusing on source control rather than treatment. To reduce toxic runoff near urban storm drains, the Department of Pesticide Regulation (DPR) has adopted new restrictions on how structural pest control businesses can apply pyrethroid pesticides. Spraying around structures to control ants is estimated to account for roughly 90 percent of outdoor urban pyrethroid use. Manufacturers' guidelines suggested spraying much wider perimeters than necessary for effective treatment, and treatment was also being done more frequently than necessary. The new restrictions limit the amount of pesticides applied to such nonporous surfaces as concrete, and they also prohibit outdoor pest control applicators and maintenance gardeners from spraying when it rains. These restrictions require some additional training of pest control professionals to understand the new regulations, and they are estimated to potentially raise business costs slightly—estimated at approximately $140 dollars a year per business, or less than $250,000 a year for businesses within the Delta watershed. There is likely to be a total net savings for individuals and property owners because of reduced chemical use (California Department of Pesticide Regulation 2012). In contrast, treatment to remove a range of toxic substances has been estimated to be very costly (tens to hundreds of millions of dollars per creek, or many hundreds of millions – or billions – for the entire watershed), and it is not a very effective approach for such chemicals as pyrethroids, which are harmful even in very small concentrations.[12]

Action #2: Reduce farm pesticide discharges (under way, $$–$$$)

Farm pesticide discharges also can harm native fishes and the food webs on which they rely.[13] Farm pesticide applications within the greater Delta watershed are already regulated to some extent. For instance, Sacramento Valley rice farmers now keep water containing certain chemicals on their fields until the active ingredients have diminished. Likewise, farmers are sometimes required to switch to other pesticides to reduce harm to wildlife.[14] However, there are still concerns about the toxic effects from some pesticide discharges on aquatic wildlife. Reducing agricultural discharges of pesticides would likely involve reducing applications and making other changes in farming practices (shifts in crop mix and, in the extreme, reducing irrigated land area). The estimated costs of regulations to limit pesticide discharges and air pollution from agriculture differ widely by location and especially by crop group—ranging from $50 to $1,000 per acre per year (Asano et al. 2007; Atwater, Dryde, and Grebbien 1998; Au 1988; Paggi, Noel, and Yamazaki 2009). Even at the low end of this range, if regulations were applied to all 3.9 million irrigated acres within the watershed, this would result in annual costs of roughly $195 million.

However, there are current examples of lower-cost steps that can reduce pesticide and other agricultural discharges. The CVRWQCB has recently adopted regulatory requirements as part of the Long-Term Irrigated Lands Program, which includes control of pesticide discharges. The proposed waste discharge requirements

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[12] Discussions with Kelly Moran, environmental consultant, February 2013.
[13] For example, Bennett, Ostrach, and Hinton (1995) found that herbicides present in spring drainage water from rice fields likely killed a high proportion of larval striped bass in the Sacramento River; this impact disappeared when pesticide use practices were changed.
[14] Classically, the use of chlorinated hydrocarbon pesticides was largely banned following revelations of their great harm to wildlife by Rachel Carson in her 1962 book *Silent Spring*.

address both surface water quality and groundwater quality, and they build on an existing program for surface water quality. Costs associated with this program include both administrative and monitoring costs and direct grower costs. Costs to growers result from the creation of individual farm plans and management practices to address discharges. For the Eastern San Joaquin River watershed, the new waste discharge requirements resulted in a total increase in cost of $5.20 per acre (including $2.50 per acre of nongrower costs) and for the Tulare Lake region, $3.40 per acre (including $1.10 per acre for nongrower costs) (Central Valley Regional Water Quality Control Board 2012). If regulations were applied to all 3.9 million irrigated acres in the Delta watershed, additional grower costs from such regulations would be roughly $10 million per year, with an additional $5 million to $10 million in monitoring and administration costs.

Action #3: Reduce toxic substance discharges (under way, $$–$$$)

This action area involves reducing discharges of chemical and biological contaminants that raise public health and environmental health concerns, such as pharmaceuticals, personal care products, and newer chemical compounds. These "emerging contaminants" are generated from urban discharges (particularly sewage) and agricultural runoff.

Removing such agents from urban sewage can be costly. One approach is to use reverse osmosis (RO) to produce recycled water (largely to potable standards). For the three major urban systems draining into the Delta (Sacramento Regional, Stockton, and Modesto), the costs of such a conversion would be roughly $300 million per year, assuming that about a third of all applied water in the three areas (456,000 acre-feet [af] per year) were treated with RO at an annual cost of $2,000 per af of water.[15] Some of this high-quality water could be resold, partially offsetting these higher treatment costs. Again, source control can be much less costly. Many wastewater agencies now conduct outreach to encourage customers not to dispose of unused pharmaceuticals in drains and toilets. Outreach expenses may range from tens of thousands to hundreds of thousands of dollars per year. However, this method cannot completely eliminate such discharges, some of which are present in human waste.

As noted above (#2), reducing farm pesticides or using more environmentally friendly pest control practices could lower crop yields or raise the costs of farming (in our examples, by $10 million to $195 million per year if applied to all irrigated acreage within the watershed).

Action #4: Reduce urban point discharges (under way, $$–$$$)

The principal focus of discussions regarding urban point source pollution in the Delta has been the Sacramento Regional County Sanitation District (SRCSD), which treats wastewater for most communities within Sacramento County as well as for the city of West Sacramento (Yolo County). The concern has been increased levels of ammonium that the existing facilities are releasing into the Delta, as the population in the service area has grown. Ammonium can affect the productivity of the food web that supports fish in the Delta through adverse effects on phytoplankton (Parker et al. 2010). In response to these concerns, CVRWQCB issued an order in December 2010 requiring that SRCSD upgrade its facility to remove nitrogen and install tertiary treatment, and this decision was affirmed by the State Water Resources Control Board (SWRCB) in late 2012.[16] This investment is expected to reduce ammonia nitrogen concentration from April

[15] This is the middle range of desalination costs, which use RO technology, presented in the latest update of the California Water Plan (California Department of Water Resources 2009).

[16] The SWRCB affirmed the regional board's decision (October 20, 2012) and issued a State Board's Order on December 4, 2012. SRCSD has filed a legal challenge to the order (R5-2010-0114-01).

to October by 93 percent.[17] This is already a standard level of treatment in most urbanized areas of the state (including two other major dischargers within the watershed, the cities of Stockton and Modesto), but it will substantially increase costs for SRCSD ratepayers. SRCSD's initial cost estimate for the requisite facility modifications range was $2 billion in capital costs plus an additional $77 million per year in operations and maintenance costs—or a total to $175 million on an annualized basis. At the time, the SWRCB's consultants reviewed the costs and argued that they would likely be 35 percent lower, and, following a pilot project, the district recently announced that costs might be only half the original estimates (Brannan 2013). If SRCSD can sell some of the resulting highly treated water, as permitted by recently adopted legislation (Assembly Bill 134, 2011), this could further lessen net costs to the district. Overall costs of this action would increase if two smaller wastewater systems located at the Delta's western edge are also required to upgrade to tertiary treatment.[18]

Action #5: Reduce farm fertilizer discharges (planned, $$$)

Farm fertilizer discharges contain nitrates and phosphorus, both of which can be harmful to native Delta fishes by creating harmful algae blooms and lowering water quality (e.g., by reducing dissolved oxygen levels needed for fish). Low dissolved oxygen levels are occasionally a problem in the Stockton Ship Channel, in particular. Although these discharges are currently monitored, they are not subject to regulatory controls.

Reducing fertilizer discharges into the Delta watershed could concern upstream agriculture in the Sacramento Valley (Sacramento River and its tributaries) and the San Joaquin Valley (San Joaquin River and its tributaries) as well as agriculture within the Delta itself. No direct estimates are available for this watershed. However, a recent study provides cost estimates of reducing nitrate loads to groundwater in the Tulare Lake hydrologic region (Medellín-Azuara et al. in press). Although this region, which includes portions of Kern, Kings, Tulare, and Fresno Counties, does not drain into the Delta in most years, the agricultural systems there are sufficiently similar to those in the greater Delta watershed to provide some guidance on costs.

Practices to increase nitrogen use efficiency by crops (thereby reducing nitrate loads) include improved infrastructure, scheduling, and monitoring (Medellín-Azuara et al. in press). Some reduction in irrigated crop area is likely to occur because these practices increase crop production costs. In the Tulare Lake basin, reducing applied nitrogen by 9 percent was estimated to reduce nitrate load to groundwater by 25 percent. This action was estimated to result in a 4.1 percent reduction (133,000 acres) in total irrigated crop area within the basin and a 3.5 percent reduction in net farm revenues (or nearly $160 million per year in 2008 dollars). Within the Delta-draining watershed, a comparable range of fertilizer application reduction (around 9%) with similar application rates might involve a reduction of 161,000 acres of irrigated lands and $195 million of annual declines in net farm revenues (or returns to land and management). This might be an overestimate, given the typically higher crop values in the Tulare basin relative to farming within much of the Delta watershed. However, the costs of reducing nitrate load are not constant; larger reductions would generate increasingly higher reductions in irrigated acreage and greater revenue losses. Additional costs might be entailed for reductions in discharges of phosphorus.

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[17] Average monthly discharges of ammonium nitrogen will be reduced from 24 mg/l to 1.5 mg/l as nitrogen to meet the effluent limitations of the NPDES permit.

[18] The Delta Diablo Sanitation District (near Pittsburg in the west Delta) and the Central Contra Costa Sanitary District (near Martinez at the west end of Suisun Bay) also still use secondary treatment and contribute to high nutrient levels within the Delta when the tides move the discharges upstream. These wastewater agencies are located within the boundaries of the San Francisco Regional Water Quality Control Board.

Action #6: Dilute pollutant loads with increased freshwater flows (considered, $$–$$$)

As an alternative to reducing discharges directly (#1—5), some observers have suggested that harmful chemicals could be diluted with additional freshwater flows. Such dilutions are not allowed under the treatment order for the SRCSD (#4), nor would they be practical, given the very high reductions in ammonium nitrogen that are being called for (> 90%). However, dilution is a potential method under consideration for some nonpoint sources, including agricultural runoff into the lower San Joaquin River (which now functions largely as an irrigation drainage ditch during summer months). Using the Statewide Agricultural Production (SWAP) model calibrated to land and water use in 2005, a 10 percent dilution requires about a 10 percent increase in clean water inflows. If this increased inflow is obtained by reducing all water sources for irrigated agriculture by 10 percent—or about 587 thousand acre-feet (taf) per year and 329 taf per year for the Sacramento and San Joaquin River basins, respectively—annual crop revenue losses would be on the order of $100 million and $60 million (in 2008 dollars) for each basin, or $28 million and $47 million, respectively, of lost returns to land and management.

Direct Fish Management

The next seven actions are direct fish management activities relating to fish harvest (commercial or sport), hatcheries, or prevention of entrainment by screening water diversion points.

Action #7: Truck juvenile salmonids around the Delta (under way, $)

Juvenile salmon currently have high mortality when migrating through the central Delta on their way to the ocean. This has led to some efforts to truck hatchery fish from the hatcheries to areas closer to the ocean. One of the two largest hatcheries—the Feather River Hatchery, operated by the state Department of Fish and Wildlife—currently trucks about 6 million fish per year around the Delta, at an annual cost of roughly $60,000 (including wages and fuel, truck rental, trailer maintenance and oxygen and acclimation net pens).[19] The other hatcheries, including the large Coleman National Fish Hatchery and three smaller ones (Nimbus, Mokelumne River, and Merced River), typically plant their production in their adjacent rivers. Assuming similar costs, expanding the program to cover all hatchery fish would cost an additional $145,000 per year, or a total of about $205,000 per year.

Action #8: Increase enforcement to prevent poaching (under way, $)

Hiring more wardens may increase surveillance to prevent poaching (illegal fishing) of native fish. Poaching is regarded worldwide as a major problem for sturgeon conservation (Pires and Moreto 2011), and reducing poaching on green and white sturgeon within the Delta could be effective because these fish are slow to reach maturity, live a long time, and have high fecundity. (Scientists we surveyed ranked this action more generally as likely to have a low impact on the Delta's native fishes, likely reflecting the view that poaching is not a major issue for other Delta fishes such as salmon and steelhead; see Hanak et al. 2013a, 2013b.) Assuming that salary, benefits, and operational support cost about $200,000 per warden per year, the annual cost of hiring 12 more wardens would be roughly $2.5 million.

Action #9: Increase screening of water diversions (under way, $–$$)

In recent decades, significant investments have been made to screen water diversions within the greater Delta watershed (and particularly within the Sacramento Valley) to reduce entrainment of fish and larvae at

[19] Information provided by A. J. Dill, assistant hatchery manager, January 2013.

intakes. Meta-analysis evaluating the effectiveness of fish screening diversions suggests that screens, particularly on large diversions, may have slowed declines in native fish populations (Moyle and Israel 2005). Most remaining unscreened diversions are smaller, located both upstream and within the Delta, and the benefits of such screening are less certain (Moyle and Israel 2005). The approach to the large pumps in the south Delta also remains unscreened.

Capital costs of fish screens vary widely, with much higher unit costs for larger intakes (Table 2). Proposed screened intake facilities for the Clifton Court Forebay—near the south Delta pumps—are as high as $340 million for a 2,000 cubic feet per second (cfs) capacity.[20] Fish screens at Rock Slough intake for Contra Costa Water District (CCWD) (700 cfs) cost approximately $30 million. For smaller CCWD intakes, such as the Middle River in Victoria Canal (250 cfs), costs were about a million dollars including fish screen and cleaning rake materials and installation, whereas the total project cost was $25 million for the intake.[21] CCWD monitoring suggests that these investments have been quite effective at reducing entrainment.[22] In annualized terms, even the larger screens have relatively modest costs—under $20 million for the Clifton Court Forebay project and $20,000 apiece for the smaller screens.[23]

TABLE 2
Costs of fish screens on selected intakes

	Installation Cost ($ millions)	Capacity (cfs)	Unit Cost ($1,000/cfs)	Annualized Cost ($ millions)
Clifton Court Forebay	200–340	2,000	100–170	10–17
Rock Slough (CCWD)	30	700	43	1.5
Victoria Canal (CCWD)	1	250	1	0.02

SOURCE: CH2MHill 2009 (for Clifton Court Forebay) and information supplied by Contra Costa Water District.

NOTES: The numbers for the two CCWD intakes are actual costs; the estimate for Clifton Court Forebay was for a proposed pilot investment at the approach to the south Delta pumps.

Action #10: Develop new conservation hatcheries to support native fish (under way, $$)

Conservation hatcheries have been suggested as a way to preserve genetic diversity for delta smelt, longfin smelt, and such other endangered fishes as coho salmon, given their highly compromised conditions in the wild. This could be considered an interim measure, complementary with longer-term investments in habitat and other conditions that will improve conditions for these fish in the wild. Because there are no fisheries for these fish, the costs of such a policy are limited to the investments and operations of the hatchery itself. Currently, the University of California, Davis runs a small hatchery for delta smelt for research purposes in Rio Vista, but a much bigger facility would be needed for the conservation purposes considered here. A new large conservation hatchery in Rio Vista might be comparable in scale to the Southwest Native Aquatic Resources and Recovery Center in New Mexico (formerly Dexter National Fish Hatchery and Technology Center), which has served since 1974 as emergency response and housing for endangered fish species. Such a

[20] In the scoping study that produced this estimate (CH2MHill 2009), the assumption was that screens would be needed mainly during periods when State Water Project (SWP) operations were reduced because of operations to protect endangered fish. Total export capacity at the SWP export pumps is 6,000 cfs, and Central Valley Project (CVP) pumping capacity is 4,600 cfs.

[21] The entire construction cost of the intake included pumps and motors, electrical, setback levee, surge protection, and the intake structure itself.

[22] Monitoring during 15 years of fish screens of CCWD intakes, including Rock Slough, Old River, Middle River, and Mallard Slough, reports two delta smelt larvae at the Old River and some dozens of splittail larvae and some tens of delta smelt larvae in Mallard Slough. Preventive measures and corrective actions have been taken over time in scheduling pumping with good results in terms of no fish or larvae trapped.

[23] For smaller agricultural diversions such as those in the Delta (where there are an estimated 1,800 diversions, mostly unscreened), capital costs are lower but there are significant additional energy costs to continually clear the siphons of debris. Consolidation of intakes would likely be needed to do this cost-effectively.

hatchery might cost about $200 million, with $10 million in annual operating costs including net changes in operating costs at other hatcheries, for total annualized costs of $20 million.

Action #11: Reduce harvest of anadromous fish (under way, $$)

Reducing the harvesting of salmon and steelhead fish would likely reduce revenue for commercial and recreational fisheries. Estimates of the cost of the recreational and commercial salmon fishery closure in 2008 and 2009 relative to 2004 and 2005 (Michael 2010) indicate direct revenue losses of roughly $35 million per year to the sector or losses of roughly $18 million in value added.[24] (For more discussion of the closure, see #14.)

Action #12: Trap and truck fish around dams (considered, $)

Recently, proposals have been floated to trap and truck salmon around dams to provide them with access to their former upstream spawning areas, such as on the Yuba and McCloud Rivers where some river reaches above the dam have good spawning and rearing habitat. The approach is used in parts of the Pacific Northwest. Trapping and trucking naturally spawning salmon might work reasonably well for moving adult salmon to spawning areas, but it can be more challenging to trap and transport juvenile salmon moving downstream around dams. Cost considerations of a trap and truck program include transfers per day, kind of trap, distance between capture and release points, reservoir and dam characteristics, necessity of fish handling and process, and vehicle characteristics and use.[25] Considering these factors, this might quadruple the costs relative to trucking hatchery salmon around the Delta (#7)—to as much as $800,000 per year for each river. Thus, a program involving three rivers (e.g., the upper Sacramento, McCloud, and Yuba Rivers) would cost around $2.4 million per year.

Action #13: Allow unrestricted fishing on nonnative predatory fish (considered, $$)

Currently, anglers face both catch and minimum size limits when keeping striped bass and largemouth bass, two alien fishes that are the center of the popular Delta recreational fishery. Striped bass and other piscivorous fishes are predators on out-migrating juvenile salmon in the central Delta. Some stakeholders have called for less-restrictive regulations for striped bass fishing to reduce predation on juvenile salmon, ideally taking away all protection for them.[26] Here, we consider unrestricted fishing on all potential nonnative fish predators on salmon: striped bass, channel catfish, largemouth bass, and other fishes.[27] This action could initially boost revenues for Delta-based recreational fisheries but could also lead to eventual declines, because sports fishermen would presumably lose interest when populations decline. Medellín-Azuara et al. (2012) estimated that the Delta's water-based recreation sector, much of which is related to sports fishing, generates about $177 million per year in direct revenues (expenditures at marinas and related food, lodging, and retail establishments). A 20 percent reduction in this sector's total revenues would amount to losses of roughly $35 million per year in revenue and about $18 million in value added. Of course, if the measure were effective in improving salmon populations, there could be some offsetting effects from increased recreational fishing for salmon.

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[24] This study presented total costs, including spillovers, for two years at roughly $118 million. To obtain the annual direct costs, we divided by 2 and then assumed an output multiplier of 1.7.

[25] Personal communication, Stacy Li (retired, NMFS), December 2012.

[26] The Coalition for a Sustainable Delta was also responsible for a 2008 lawsuit against the state Department of Fish and Game (DFG), arguing that predation by nonnative striped bass was a major contributor to the decline in salmon populations. In a 2012 settlement agreement, DFG agreed to reduce restrictions on striped bass fishing, but this action was not approved by the state Fish and Game Commission, which regulates hunting and fishing licenses. (The department was renamed Department of Fish and Wildlife [DFW] in January 2013.)

[27] For predator control to be effective, control programs would also be needed for predatory birds (terns, cormorants, etc.) and mammals (otters, sea lions). Changing federal laws to allow large-scale killing of such charismatic species is unlikely, so no cost estimate is provided.

Action #14: Manage hatcheries to separate hatchery fish from wild populations (considered, $$)

Hatcheries were established to mitigate the negative effects of dams on migratory salmon and steelhead trout, because dams cut off access to their natural upstream spawning grounds. However, recent evidence points to unintended harm from hatcheries to the wild populations of these species (Williams 2006; Lindley et al. 2009; Carlson and Satterthwaite 2011). Populations of winter-run and spring-run Chinook salmon—both listed under federal and state Endangered Species Acts—are partially supported by hatchery production, but substantial recovery has not occurred. The main remaining run is fall-run Chinook, which now consists almost entirely of fish of hatchery origin or progeny of hatchery fish. The result is a more genetically uniform (and presumably more behaviorally uniform) population throughout the Central Valley. These fish are poorly adapted for surviving periods of adverse conditions in the ocean, resulting in yo-yo population dynamics. Salmon numbers were so low in 2008 and 2009 that the fishery was closed, whereas in 2012, the numbers were the highest in decades.

Recent proposals have suggested that the effectiveness of hatchery operations in California can be improved by managing hatcheries that support commercial and residential fisheries in ways that isolate them from wild populations (Hanak et al. 2011). In the extreme, hatcheries supporting the fisheries would be closed, and regulated rivers would be managed better to support wild salmon, perhaps even by removing some dams (#28). Such a strategy could result in the closure of the commercial and recreational fisheries for Central Valley salmon and steelhead for many years, until wild populations recovered. According to Michael's (2010) estimate of losses from the complete closure of California's salmon fisheries in 2008 and 2009 (#10), the complete closure of the fishery would have annual losses on the order of $35 million in revenues and $18 million in value added (relative to 2005 baseline conditions).

An alternative would be to continue some fishery-oriented hatcheries but in a more segregated manner. Hatcheries run entirely to support fisheries would presumably be located near the ocean and operated to minimize the straying of hatchery fish and their interbreeding with wild fish. For example, all fish would be marked so that strays could be removed from upstream areas and fisheries could concentrate on marked fish. Most rivers would be reserved for wild salmon, to re-initiate the processes of natural selection. As a compromise, the hatcheries on the American and Mokelumne Rivers, which are closer to the ocean than more upstream hatcheries, could be managed for fisheries, in part by trucking juveniles around the estuary (#7) and making sure that only marked fish in the river are harvested or used for hatchery purposes. Relocation and/or closure of the Coleman, Feather River, and Merced Hatcheries as production facilities would be necessary because of their distance from the ocean and proximity to remaining natural spawning areas. Alternatively, they could be operated as conservation hatcheries (#10). Such a strategy could maintain the commercial and recreational fishery (albeit perhaps at reduced levels). Cost would include relocating equipment and staff—perhaps 50 percent to 75 percent of the costs of building a new facility, or $100 million to $150 million (#10)—or $5 million to $8 million in annualized terms per facility.

Flow Regime

The following seven actions are approaches to mitigating ecosystem stress resulting from alterations in flow characteristics to support water supply and flood management. Water management facilities and operations in this watershed (including upstream dams and diversions, as well as in-Delta diversions and exports) have changed the volume, timing, hydraulics, sediment load, and temperatures of water, adversely affecting conditions for native fishes.

Action #15: Add gated structures within the Delta to improve fish passage (under way, \$–\$\$)

Gates and barriers are already used in some parts of the Delta to improve fish passage. For instance, the Delta Cross-Channel near Walnut Grove is closed during some periods of the year to support salmon migration. As part of an overall ecosystem management strategy, other barriers might help keep native fish in favorable habitat areas (and out of inhospitable areas).

The recently considered (and rejected) "Two Gates" project gives a rough estimate of what other gates might cost. This project, a joint initiative of the Department of Water Resources (DWR) and the U.S. Bureau of Reclamation (USBR), was intended to improve delta smelt survival in the Delta by placing gates in the Old River between Bacon Island and Holland Tract and in Connection Slough between Mandeville and Bacon Islands. The project had estimated capital costs of \$35 million, including \$5 million for planning and development.[28] Annual operating costs were estimated at \$4.4 million, including environmental monitoring costs.[29] This yields an annualized cost of roughly \$6 million.

In addition to the direct costs of constructing and operating the barriers, there can be additional costs or benefits to water users from gate operation. For instance, closure of the Delta Cross-Channel gates reduces water quality (increasing salinity) reaching the south Delta export pumps. The Two Gates project was intended to improve conditions for delta smelt while facilitating higher export levels than some other management alternatives.

Action #16: Reduce entrainment at export pumps (under way, \$\$)

As noted above in the discussion of fish screens (#9), some recent proposals have been floated to consider the partial screening of the approach to the export pumps at Clifton Court Forebay as a way to reduce entrainment. That screen, estimated to cost between \$200 million and \$340 million, would have the capacity to handle low flow periods only (2,000 cfs, or one-third of SWP pumping capacity). On an annualized basis, it would cost under \$20 million per year.

However, many observers consider fish screens to be a relatively ineffective tool for reducing entrainment at these large pumps. The fish that are salvaged (captured) near the pumps also have high mortality, screens have little benefit for fish larvae too small to be effectively screened, and pumping areas have high rates of predation, with the result that few native fish that arrive near the pumps make it back to their natural spawning and migration areas. This makes reducing exports, or changing export patterns or location (e.g., with a new canal or tunnel—#21), a potentially more effective way to reduce the broad effects of fish entrainment at the pumps. The critical times tend to be from January through May, whenever delta smelt, splittail, or salmon are present. The recent reductions in exports have been designed in part to reduce entrainment and the harmful patterns of reverse flows on some channels in the south Delta. According to the CALVIN estimates presented below (#17 and #18), these may cost on the order of \$50 million per year in reduced net farm revenues and urban sector shortage costs. Further reductions would cost more per acre-foot.

Actions #17 and #18: Reduce Delta exports and increase net Delta outflows (under way, \$\$–\$\$\$)

Increasing net outflows and reducing Delta exports are two closely related actions. Net Delta outflows can be increased in one of three ways: by increasing releases from upstream reservoirs, by reducing upstream diversions, and/or by reducing exports. Increasing net outflows from the Delta may help improve aquatic

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[28] www.water.ca.gov/deltainit/docs/TwoGatesProject.pdf

[29] Personal communication, Dennis Majors, Metropolitan Water District of Southern California, December 2012.

habitat for native fish species, by helping to move native species toward the low salinity "mixing zone" at the Delta's western edge. In addition, reducing exports can reduce harmful direct and indirect effects of the export pumps in the south Delta. These include entrainment of fish and larvae by the pumps and disturbance of the Delta's natural flow patterns, which can adversely affect the food web and draw native fish into inhospitable areas. Under the current regulatory rules, Delta exporters are required to meet water quality standards in the Delta (including net outflow levels), but this situation could change in the future to one in which upstream diverters also bear some of this responsibility.[30]

Reducing either upstream or export diversions has costs for water users, but the extent of these costs depends on both the size of the cutbacks and whether the burden is on export users only or on all diverters. Tanaka et al. (2011) demonstrate this using the CALVIN model of California's water system, which looks for least-cost management alternatives. This model assumes that managers make long-term changes to achieve the most economically efficient outcomes, and its baseline assumption is that there are no institutional barriers (or "transactions costs") to making the most efficient use of California's integrated water network, including economically worthwhile water trades. Tanaka et al. directly compared the costs of reducing exports and more generally reducing diversions for very large increases in net Delta outflows. With water demands for 2050 and historical hydrology, increasing net outflows by roughly 6 million acre-feet (maf) per year (or roughly 45% relative to a pre-2007 average of 13 maf per year) would increase annual statewide water user costs by roughly $1 billion, or $185 per af (2008 dollars). The costs would be higher ($250 per af and roughly $1.5 billion per year) if increased outflow came entirely from reduced exports, because there are some lower-cost opportunities to reduce water use upstream of the Delta. (This volume of reductions would end exports entirely.) Costs would be higher still ($425 per af, or $2.5 billion per year) if, in addition, water trading were restricted among water users south of the Delta.

The per-acre-foot costs would be much lower for smaller increases in net outflow, as long as the least valuable uses of water were reduced first. For instance, increasing outflows by 1.1 maf per year (9%) entirely through export reductions (from a pre-2007 base of 5.9 maf per year) would cost just under $50 million per year, or roughly $40 per af, mostly from reduced agricultural production. This level of export reductions corresponds roughly to the current level of average exports authorized under regulatory requirements in place since 2008 (about 4.7 maf per year). Further reductions in diversions may be called for in the future to support native fish. With another 2.4 maf per year in reduced diversions (or 3.5 maf per year total reductions relative to the 5.9 maf per year baseline) achieved solely by export reductions, costs to water users would rise to $350 million/year ($100 per af on average). These costs would lessen if some reductions came from upstream users and if urban areas are successful in reducing per capita water use, but they would increase with a drier, warmer form of climate change (Hanak et al. 2011, chapter 6).

The cost estimates presented here include operational costs from such alternative sources as recycled water and desalination (mainly urban areas) and scarcity costs in both urban and farm sectors (including lost income for farm managers and owners from reduced output). There would be additional costs to regional economies in agricultural areas (Lund et al. 2010).

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[30] See the discussion of regulatory issues for Delta stressors in the companion report to this study, *Integrated Management of Delta Stressors: Institutional and Legal Options* (Gray et al. 2013).

Action #19: Improve flow regime upstream of the Delta (under way, $$–$$$)

Changes in upstream flows are sought mostly to support fall-run Chinook salmon, the most prevalent remaining salmonid in the watershed. This requires a pulse in the fall (October–November) to cue adult salmon to move up from the estuary and then sustained higher flows for spawning, incubation, and rearing, with another pulse in April–May to cue and push the juveniles downstream. For spring-run Chinook, deep pools and sustained higher flows are needed all summer, to keep temperatures cool (as proposed for the San Joaquin River system). Winter-run Chinook need higher flows mainly through July for incubation of eggs and rearing of young in the river below Shasta Dam.

To develop a rough approximation of these types of improvements, we use the SWAP model and assume a cutback of water from all sources (surface and groundwater) by 20 percent (or about 2.4 maf per year) in dry and critical years—which represents about 40 percent of the historical record (1921–1982) for the Sacramento and San Joaquin River systems. Such a cutback (with no groundwater overdraft allowed) could cost around $235 million for the Sacramento River basin and $525 million for the San Joaquin River in lost value added from agricultural activity in these years. Averaging over all years (including normal and wet years without cutbacks), the combined annual cost would be roughly $305 million in lost value added. These costs would be lower if the measures were implemented more selectively, e.g., on certain tributaries and not others. Moreover, the environmental value of this water could be increased if it were also used to support other conservation measures (e.g., floodplains—# 27). Costs for more environmentally patterned upstream flows might be higher or lower with the construction of additional upstream storage.

Action #20: Pattern Delta flow variability to support native species (considered, $$–$$$)

More natural flow patterns, particularly when accompanied by more natural habitat patterns, would provide several important benefits: (i) behavioral cues expected by native fish, (ii) assistance with migration, (iii) more natural, seasonal patterns of aquatic habitat and food, and (iv) relief from predators (Jeffres, Opperman, and Moyle 2008; Moyle, Crain, and Whitener 2007; Sommer et al. 2001).

Flows through the Delta from the Sacramento and San Joaquin Rivers today largely depend on both natural high flow events and releases from upstream dams. Historically, the highest flows followed winter/spring storms (Sacramento River) and spring /summer snowmelt (San Joaquin River), with September and October typically being months of lowest outflows. The life histories of native fishes are adapted to the historical flow regime. Most native fishes spawn in spring in response to high flows and flooding, although the four runs of salmon reflect specializations to spawn at different times of year. Spring-run Chinook, for example, spawn in fall when flows are low because during high flows in spring, they migrate to high-elevation areas, where they remain all summer. Each species and run have a somewhat different spawning time and place, so different types of flow years would be optimal for different species. In general, the most benefit to the most species comes in years when flows are high enough to start inundating floodplains in January or February, with large pulses that maintain or expand flooded areas into April and May. In the Delta, this means maintaining the low salinity mixing zone in Suisun Bay and vicinity during this period, although in high snowfall years, it may have been kept there much longer before human development of the watershed. Inflows would have been declining or minimal in August–September, but fall-run Chinook may have been entering in October as temperatures cooled. For most non-salmonid native fishes, lower flows in June–October would have been beneficial for the rearing of young, because of warmer temperatures.

Re-patterning flows to support fish would likely impose some costs on agricultural and urban water users, as some of these more natural flows will become unavailable for diversions. For example, maintaining high flows to support seasonal flooding of floodplains or wetlands is likely to require higher springtime flows (which are less easily diverted downstream for human uses) and correspondingly less water in storage for summer uses. Additional in-Delta or near-Delta storage might help recapture such flows, though whether this would come at overall lower or higher costs is unclear at this point.

One approach to restoring more natural flow patterns is to require some proportion of unimpaired flows for any given year from the Delta-draining tributaries. (Unimpaired flows are the estimated flows that would have occurred without dams or diversions.) A recent draft research report for the lower San Joaquin River prepared by the State Water Resources Control Board (2012) indicates that having 60 percent of unimpaired flow in three tributaries (the Merced, Tuolumne, and Stanislaus Rivers) may result in average reduced diversions of 610 taf per year. (Current conditions have on average between 20 and 30 percent of unimpaired flows.) The hydrologic simulation used CALSIM II current conditions and a water balance approach, with limits on minimum and maximum flows in the tributaries and water storage in reservoirs to secure 60 percent of unimpaired flows.[31] The system would be reoperated only in the late winter and spring (February through June), operating under current conditions during the rest of the year. This change could cause direct revenue losses of roughly $125 million per year, roughly 60 million per year in value added or $95 per af of reduced diversions compared to current average diversion levels on these rivers. If diversions were restricted to achieve 40 percent of unimpaired flows, total direct value added losses would fall to roughly $20 million annually. Additional costs would be incurred if a similar approach were applied to the Sacramento River tributaries.

Action #21: Divert Delta exports through a canal or tunnel (considered, $$$)

Diverting Delta exports through a canal or tunnel that taps water from the Sacramento River in the north Delta could provide benefits for native fish species by reducing entrainment at the south Delta pumps (#21) and allowing a more natural flow patterns within the Delta (#17). However, this investment—a cornerstone of the BDCP now under development—is also anticipated to provide net benefits to water users in terms of water supply reliability and improved water quality. (Unless this is true, water users will be unwilling to pay the full cost of a facility, an underlying assumption of the project to date.) The 2010 draft of the BDCP project description[32] provided a midpoint investment cost estimate for a new conveyance facility of $12.7 billion, with annual operating costs (including power, operations and maintenance, capital replacement, and property tax) of roughly $85 million per year—or $720 million per year in annualized terms. Although this is the most costly action among those considered here, it is not strictly comparable with the costs of other actions, since these expenditures are not strictly for environmental benefits.

Invasive Species

Alien (nonnative) species negatively affect the Delta’s native fish species by disrupting food webs, altering ecosystem function, introducing disease, and displacing native species. The four actions described here are existing or proposed ideas for reducing their effects in the Delta ecosystem.

Action #22: Directly control invasive aquatic vegetation (under way, $–$$)

The principal species of invasive aquatic weed that causes problems for the Delta’s native fishes is the Brazilian waterweed *Egeria densa*, a popular plant in home aquariums. This plant has invaded much of the

[31] CALSIM II is a model used to simulate CVP and SWP operations.
[32] http://baydeltaconservationplan.com/Libraries/Whats_in_Plan/Pages%20from%20draft_BDCPreport_11292010_ClickableLinks7-Ch_8.pdf

Delta, where it clogs channels and causes deposition of sediment, providing favorable habitat for nonnative species. It is also an impediment to navigation. The California Department of Boating and Waterways (DBW) (2006) estimates that in 2006, about 11,500 to 14,000 water acres—or 17 to 21 percent of the Delta's water area—were infested with *Egeria*, with continuing rapid expansion. DBW has been conducting some limited control efforts using herbicides since 2001 and spent about $4 million annually to treat an average of roughly 570 acres between 2003 and 2005.[33] In 2006, the program set a goal of expanding the number of priority sites and potential acreage covered from 1,733 acres per year to 3,000–5,000 acres per year (California Department of Boating and Waterways 2006). If program administration costs remain as high (environmental monitoring, regulatory compliance, and surveillance often consumed 65% of program costs), attaining the 3,000–5,000 acre goal would cost about $20 million to $35 million annually.[34] The benefits would be mainly to recreational boating, although presumably this could also increase flowing and open-water habitat for salmon and smelt and reduce predation by resident alien fishes.

Action #23: Increase actions to prevent new invasions (under way, $$)

Although new invasions are inevitable, concerted actions by the numerous state and federal agencies with some management role could help reduce the likelihood and effects of these invasions.(Hanak et al. 2011, chapter 5).[35] Prevention actions would include aggressively inspecting boats and enforcing no-tolerance limits for aliens in the ballast water of ships and other vectors; creating and enforcing an approved ("white") list for pet, aquaculture, and bait organisms allowed for sale (and prohibiting others); creating an invasive species response team to react quickly to new, potentially harmful invasions; and other priority actions recommended in the *California Aquatic Invasive Species Management Plan* (Department of Fish and Game 2008) and by the Ecological Society of America (Lodge et al. 2006). As a very rough estimate, administering such actions might cost on the order of $10 million to $25 million per year (for roughly 50 to 125 staff plus operational support, using same per capita cost estimates as in #8). Additional costs would be incurred by the shipping industry to comply with stricter ballast water controls.

Action #24: Directly control invasive clams (conceptual, $–$$)

Two species of invasive clams have created less favorable conditions for native fish species, especially delta smelt and longfin smelt. The Asiatic clam is now abundant in the fresh water of river channels and flooded islands within the Delta, and the overbite clam has invaded the brackish waters of Suisun and San Francisco Bays. Both clam species are filter feeders, and they greatly reduce plankton populations that are an important part of the food web for native fish species.

No treatment programs have been attempted for these clam species within the Delta or the San Francisco Estuary. One experimental option would be to dredge clams during the winter. Dredged material would have to be filtered of clams and then returned or deposited elsewhere, and this action would substantially disturb substrate in the dredged areas. Dredging costs are likely to be on the order of $5 per cubic yard for re-suspension dredging. If one foot of soil were to be removed across the roughly 10,000 acres now infested and too deep to be reached by migratory diving ducks,[36] this would result in overall costs of roughly $80 million, or roughly $4

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[33] The invasive weed control program also includes water hyacinth and Asian kelp, for a total annual budget of $6 million (California Department of Boating and Waterways 2012).
[34] In particular, the permitting process has been costly and has led to substantial delays.
[35] As the example of *Egeria* above illustrates (#22), invasive species can impair navigation. If experience in the eastern United States and Europe is a guide, the costs to water project operations of coping with some expected new invasives, such as the zebra and quagga mussels, which clog canals and intakes, could run into hundreds of millions of dollars (Leung et al. 2002).
[36] Many of the shallower areas can be reached by the ducks, who feed on the clams.

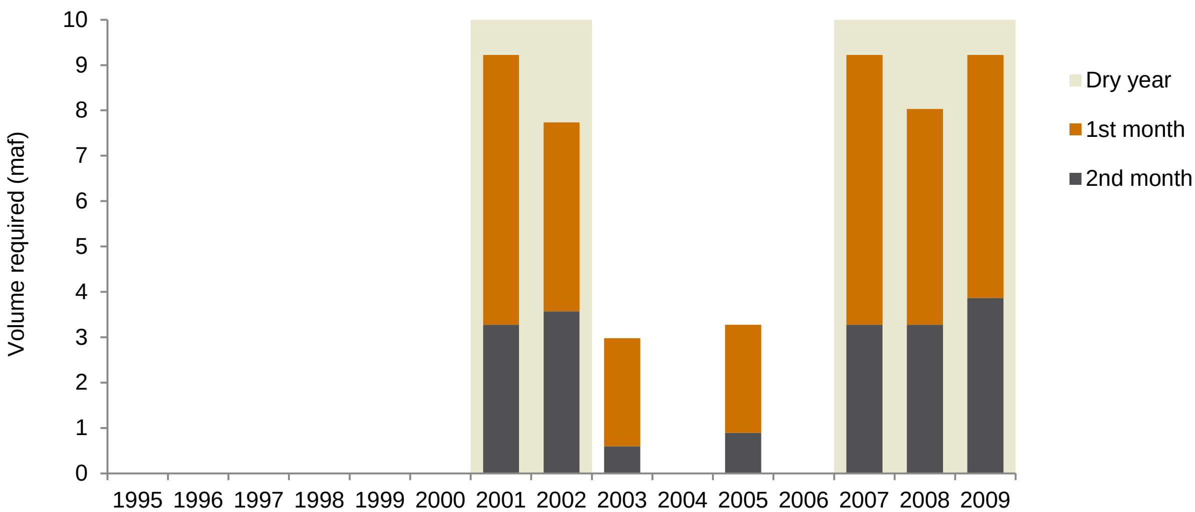
million on an annualized basis. (This estimate assumes only one treatment would be required; costs would increase if this action needs to be done repeatedly.) An experimental program would need to precede any broad application.[37]

Action #25: Increase salinity variability in the Delta (conceptual, $$$)

Before humans began diverting water from the Delta watershed for agricultural and urban uses, the Delta and Suisun Bay experienced regular seasonal fluctuations in salinity. Today, Suisun Bay becomes fresh only in wet years. Increasing salinity variability has been proposed as a way to disturb invasive species and re-create conditions more favorable and expected by native species (Moyle et al. 2010). However, this is an experimental proposal, for which details have yet to be developed.

As one possible illustration, management might seek to ensure that Suisun Bay is freshened every other spring to disturb the overbite clam that now resides in its brackish waters. Figure 2 shows the years since 1995 (the first year of modern water quality standards for the Delta)[38] when Suisun Bay freshening did not occur. To prevent the bay from remaining brackish for two years in a row, large additional spring releases would have been required in 2002 and 2008 of roughly 8 million acre-feet each year—well above the total volume of water exports. At marginal values of exported water of $200 to $300 per af (#17 and #18), this would lead to costs of $1.6 billion to $2.4 billion in the years when releases were required. Assuming that the frequency corresponded to the pattern shown here—two years in fifteen—the average annual costs would be on the order of $215 million to $320 million—perhaps higher, given the need to implement this program during multiyear droughts when reserves for human uses are at their lowest.

FIGURE 2
Volume of additional net spring outflows required to freshen Suisun Marsh



SOURCE: Author calculations using Dayflow data on flows and measured salinity data.

NOTES: The first and second months are the two lowest consecutive months required to accomplish freshening. Typically, these lie between January and May, but in 2005 this fell in May and June.

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[37] Another option might be to implement the type of experimental control program for Asiatic clam now being launched at Lake Tahoe. The method involves setting impervious mats on the shallow lakebed to prevent the clams from settling. We have been unable to obtain cost estimates for this program.

[38] The Bay-Delta Accord was adopted in the preceding year, beginning the outflow requirements for "X2" to maintain a low salinity zone in the western Delta during the spring months. These standards were subsequently formalized in water rights decision 1641 (D-1641).

Physical Habitat

Extensive human alteration of the Delta landscape and upstream river corridors over the past century and a half has resulted in the loss of physical habitat that supports native species, including upland, floodplain, riparian, open water/channel, and tidal marsh. The last seven actions are meant to mitigate these changes, addressing the impacts of levees, channelization, diking and draining of wetlands, narrowing riparian zones, shallows, and tidal and fluvial marshes both within and upstream of the Delta.

Action #26: Expand seasonal floodplains (under way, $–$$)

An important type of habitat under consideration for expansion by the Bay-Delta Conservation Plan and other efforts is seasonal floodplain.[39] This habitat, also once abundant, now primarily exists in the Yolo Bypass, as a by-product of flood protection efforts for the Sacramento metropolitan area. In a recent study, Howitt et al. (2012a) examined the economic costs of expanding this habitat with more deliberate and earlier inundation of the bypass to support native aquatic species. They examined two flow rates (3,000 and 6,000 cfs) for flooding dates ending between February 15 and May 15. The study concluded that direct annual value added losses may be as high as $4.5 million when flows are released at 6,000 cfs until May 15, and $2 million at 3,000 cfs.

Action #27: Improve or increase upstream spawning and rearing habitat (under way, $$)

Since the 1990s, some investments have already been made to improve upstream spawning and rearing habitat under both the CALFED program and the Central Valley Project Improvement Act. Gravel placement might continue in upstream locations to support spawning. (The U.S. Bureau of Reclamation has been spending about $1 million per year to add gravel to support salmon spawning below Keswick Dam on the Sacramento River and in various other locations.)[40] The cost of expanding upstream habitat by extending seasonal flooding of some areas might compare to those of expanding floodplain habitat in the Yolo Bypass (# 26)—about $5 million in lost agricultural value added per year (or about $875 per acre fallowed to create habitat). If, in addition, about 50 miles of levees are set back to create this habitat, investment costs would be on the order of $790 million, or nearly $40 million in annualized costs.

Action #28: Remove selected dams (under way, $$–$$$)

The construction of dams in the late 19th and 20th centuries cut off thousands of miles of upstream spawning habitat for California's salmon and steelhead trout populations, and dam removal has been considered in recent decades as a partial remedy to this situation (Hanak et al. 2011, chapter 5). The costs of dam removal depend greatly on the engineering challenges of the actual removal as well as on the extent of services the dam provides.[41] Although some relatively large dams in California could be removed without significantly affecting water availability, removal would generally incur substantial costs in other respects, including water quality and/or lost hydropower capacity, in addition to the direct costs of removing the facility (Null and Lund 2006). Within the greater Delta watershed, some smaller dams have already been removed to improve salmon passage, for instance on Butte Creek, Battle Creek, and Clear Creek. The National Marine Fisheries Service has recently proposed removing two dams on the Yuba River (Englebright and Daguerre Point) to improve access to upstream habitat for salmon and steelhead trout. Englebright

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[39] Expansion of Yolo Bypass habitat is included in the "near-term actions" list developed by a broad coalition of stakeholders including Delta advocates, environmental advocates, and export water users (Martineau 2012).

[40] See www.usbr.gov/mp/cvpia/docs_reports/meetings/2012/CVPIAb13PublicMtg20120315%20Gravel.pdf.

[41] American Rivers provides a catalog of past dam removal projects in the United States, including height and length of the dam, removal cost, and year removed (www.americanrivers.org).

Dam's storage capacity has been severely reduced by sediment (down 25 percent from its original capacity of 45 taf), and the dam's removal could make about 100 more miles of habitat available for steelhead trout and salmon.[42] Pejchar and Warner (2001) estimate that the removal itself would be far less costly than the loss of services the dam provides: removing Englebright might cost $85 million (including sediment removal)—or roughly $4.5 million on an annualized basis—but annual lost value added from reductions in hydropower and recreation would come to $72 million—bringing the total annualized cost to nearly $80 million.[43]

Action #29: Restore tidal marsh and shallow water habitat (planned, $$)

One main type of habitat under consideration for restoration under the BDCP is tidal marsh, over 95 percent of which has disappeared as a result of dredging and draining lands for agricultural uses (Whipple et al. 2012). Restoring tidal marsh in various upland and shallow areas along the Delta's western and northern edge (Cache Slough, Lindsay Slough, Suisun Marsh, the northern half of Liberty Island, Prospect Island), Suisun Marsh and other locations may help recreate conditions more favorable to native fish species that once lived in this now scarce type of habitat. The estimated costs of land acquisition and restoration investments are roughly $20,000 per acre, plus perhaps $35–$100 per acre of annual maintenance.[44] If 30,000 acres of land are restored in this way, the total investment cost would be $600 million, and the annualized costs would be roughly $30 million, plus an addition $2 million for maintenance.[45] The land purchases would compensate landowners for the forgone net returns from farming, but there could be additional direct costs to the local economy in terms of lost farm labor and lost tax revenues for local governments (as well, as in other cases, of positive or negative economic spillover effects.)[46] Science costs to conduct adaptive management on this and other actions would be additional.

Action #30: Improve in-Delta channel margin habitat (considered, $$)

Most of the natural riparian habitat in the Delta has been replaced by rock-lined levees, which are inhospitable to native fish, providing no areas for foraging and hiding from predators. Some of the tidal marsh restoration projects (# 29) in the north Delta (e.g., McCormack-Williamson Tract) would improve channel margin conditions by breaching levees and creating more natural shallow-water habitat. But the main efforts needed to improve channel margin habitat would likely involve building setback levees along some primary corridors for fish passage. Setback levees—set several hundred feet back from the location of current levees—would make it possible to create more hospitable riparian habitat while providing continued (and perhaps enhanced) flood protection for the areas behind levees. Rough cost estimates of $3,000 per linear foot for a setback levee (including land acquisition costs, construction, acquisition of fill), suggest that it would cost about $1.4 billion to construct a setback levee corridor of 90 miles, or about $70 million per year in annualized costs.[47]

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[42] See http://walrus.wr.usgs.gov/posters/englebright.html.

[43] The Elwha River Restoration project in the Pacific Northwest—involving the removal of the Elwha dam (now complete) and Glides Canyon dam (under way) within Olympic National Park—was estimated to cost about $327 million (www.nps.gov/olym.naturescience/elwha-faq.htm) and the removal of four hydropower dams on the Klamath River is estimated to cost roughly $290 million (not counting lost hydropower costs) (http://projects.registerguard.com/web/newslocalnews/26906325-41/dams-cost-removal-salazar-dam.html.csp).

[44] Personal communication, Leo Winternitz, The Nature Conservancy, December 2012.

[45] The BDCP process has suggested much larger targets over a 40-year horizon—up to 65,000 acres (Bay Delta Conservation Plan 2009). Whether such large acreages are ecologically feasible or desirable had yet to be demonstrated at the time of this writing (February 2013).

[46] In a study for the BDCP, the Brattle Group (2013) estimates significant local economic benefits in the Delta associated with the habitat restoration activities planned under the 50-year project, as well as benefits from the construction activities associated with a new tunnel to divert exports (#21).

[47] Setback levees on Sherman Island came to $1,100 per linear foot, but these were narrow levees that experienced erosion problems, and they excluded land acquisition costs, because the land was already owned by DWR.

Action #31: Increase deep-water habitat (conceptual, $$)

Historically, the Delta did not contain deep-water habitat, and this is not necessarily the best habitat for native fish species in the Delta. However, increasing this type of habitat through permanent flooding of deeply subsided Delta islands might provide environmental benefits (Moyle 2008). The costs of these permanent island floodings varies considerably, depending on the current conditions and extent of levees, the depth of subsidence, and the value of economic activity on the islands. Considering these factors, Suddeth, Mount, and Lund (2010) suggest a set of largely agricultural islands that may not pass a business case for repair after flooding. Medellín-Azuara et al. (2012) estimate annual economic losses from permanent flooding for 19 of these islands. The costs vary widely, depending on the irrigated crop area and the value of the crops grown. For example, permanent flooding of Bacon, Quimby, and Tyler may cost $2.7 million, $0.2 million, and $6.4 million annually in lost agricultural value added, respectively. Permanent flooding of all 19 islands would lead to direct value added losses of roughly $55 million to $70 million annually.

Action #32: Increase sediment loads flowing into the Delta (conceptual, ?)

Sediment is a limiting factor for expanding suitable habitat for native species in the Delta, and particularly tidal marsh (Schoellhamer 2011; Moyle et al. 2012). Sediment loads into the Delta might be increased through complementary measures such as setting back levees (#27 and #30) and removing selected dams (#28). However, the range of potential actions is still highly speculative at this stage, making a cost estimation particularly difficult.

Conclusion

In this report, we have attempted to provide cost estimates for a broad range of ecosystem management actions intended to improve conditions for the Delta's native fish species. Although further work is needed to flesh out the details for many actions, orders of magnitudes can be estimated using existing studies, program implementation experience, and modeling results. Some major conclusions include the following:

1. There are relatively few truly low-cost actions, at less than $10 million per year. These include many direct fish management actions, some invasive species control measures, expansion of floodplain habitat, and some methods for reducing harmful urban runoff.
2. Numerous actions will require more moderate levels of spending, in the range of $10 million to $99 million, and they can be found in every stressor category.
3. The most expensive actions, coming in at more than $100 million per year, generally relate to changing flow management (which typically reduces the amount of water available for human uses) and reducing discharges (which can incur investment costs in urban areas and reduce the profitability of agriculture). Construction of a canal or tunnel to divert water exports, as proposed by the BDCP, would be the costliest action considered here (over $700 million per year), but this investment would be expected to achieve substantial water supply reliability benefits in addition to enabling more favorable flow management for native species.
4. There are still large uncertainties about how to operationalize some proposed management actions, including widely discussed measures such as restoring more natural flow patterns.

As these cost assessments show, a comprehensive management package will likely cost at least several hundred million dollars per year on an ongoing basis. For many actions, there has been an expectation that particular groups responsible for the resource would bear the costs directly—particularly the more costly actions related to discharge and flow management. Even where taxpayer funds are expected to contribute (as has been proposed for Delta habitat restoration, now included in a bond slated for the November 2014 ballot), fiscal and social realities will require implementing ecosystem management cost-effectively.

References

Asano, T., F. Burton, H. L. Leverenz, R. Tsuchihashi, and G. Tchobanoglous. 2007. *Water Reuse Issues, Technologies, and Applications.* New York: Metcalf and Eddy, Inc.

Atwater, R., F. Dryde, and V. Grebbien. 1998. *Urban Water Recycling Feasibility Assessment Guidebook*. Bookman-Edmonston Engineering, Inc.

Au, T. 1988. "Profit Measures and Methods of Economic Analysis for Capital Project Selection." *Journal of Management in Engineering* 4(3): 217–28.

Bay Delta Conservation Plan. 2009. *BDCP Aquatic Habitat Changes*. Sacramento, CA.

Bay Delta Conservation Plan. 2012. *Preliminary BDCP Draft*. Sacramento, CA.

Bennett, W. A., D. J. Ostrach, and D. E. Hinton. 1995. "Larval Striped Bass Condition in a Drought-stricken Estuary: Evaluating Pelagic Food-web Limitation." *Ecological Applications* 5: 680–92.

Brannan, B. 2013. "Sacramento-Area Sewer Rate Increases Likely to Be Lower Than First Thought." *Sacramento Bee*. February 27.

Brattle Group. 2013. *Employment Impacts for Proposed Bay Delta Water Conveyance Facility and Habitat Restoration.* Prepared for the Delta Habitat Conservation and Conveyance Program and the California Department of Water Resources.

California Department of Boating and Waterways. 2006. *Egeria densa Control Program (EDCP) Second Addendum to 2001 Environmental Impact Report with Five-Year Program Review and Future Operations Plan.*

California Department of Boating and Waterways. 2012. *Egeria densa*. Available at www.dbw.ca.gov/Environmental/EgeriaDensaGenInfo.aspx.

California Department of Fish and Game. 2008. *California Aquatic Invasive Species Management Plan.*

California Department of Pesticide Regulation. 2012. *Prevention of Surface Water Contamination by Pesticides.* Available at www.cdpr.ca.gov/docs/legbills/rulepkgs/11-004/11-004.htm.

California Department of Water Resources. 2009. *California Water Plan Update 2009*. Available at www.waterplan.water.ca.gov/cwpu2009/.

Carlson, S., and W. Satterthwaite. 2011. "Weak Portfolio Effect in a Collapsed Fish Population Complex." *Canadian Journal of Fisheries and Aquatic Sciences* 68: 1579–89.

Central Valley Region Water Quality Control Board. 2012, *Long-Term Irrigated Lands Regulatory Program.* Available at www.waterboards.ca.gov/centralvalley/water_issues/irrigated_lands/long_term_program_development/.

CH2MHill. 2009. "Low-Flow Intake Technical Analysis." Report prepared for the California Department of Water Resources, Bay-Delta Office, Fishery Improvements Section.

Delta Independent Science Board. 2011, "Addressing Multiple Stressors and Multiple Goals in the Delta Plan," Letter report to the Delta Stewardship Council. January 26.

Delta Stewardship Council. 2012. *Final Draft Delta Plan*. Sacramento: State of California (working draft). Available at http://deltacouncil.ca.gov/sites/default/files/documents/files/FinalDraft_DeltaPlan_Chapters_combined2%201.pdf.

Foe, C. 2011. Central Valley RWQCB. Testimony at the Delta Stewardship Council meeting. November 18.

Gordon, P., J. Kuprenas, J. Lee, J. E. Moore, H. W. Richardson, and C. Williamson. 2002. *An Economic Impact Evaluation of Proposed Storm Water Treatment for Los Angeles County*. University of Southern California, School of Engineering and School of Policy, Planning and Development.

Gray, B., B. Thompson, E. Hanak, J. Lund, and J. Mount. 2013. *Integrated Management of Delta Stressors: Institutional and Legal Options.* San Francisco: Public Policy Institute of California. Available at www.ppic.org/main/publication.asp?i=1054.

Hanak, E., and E. Barbour. 2005. *Sizing up the Challenge: California's Infrastructure Needs and Tradeoffs*. San Francisco: Public Policy Institute of California. Available at www.ppic.org/main/publication.asp?i=611.

Hanak, E., J. Lund, A. Dinar, B. Gray, R. Howitt, J. Mount, P. Moyle, and B. Thompson. 2011. *Managing California's Water: From Conflict to Reconciliation*. San Francisco: Public Policy Institute of California. Available at www.ppic.org/main/publication.asp?i=944.

Hanak , E., J. Lund, J. Durand, W. Fleenor, B. Gray, J. Medellín-Azuara, J. Mount, P. Moyle, C. Phillips, and B. Thompson. 2013a. *Stress Relief: Prescriptions for a Healthier Delta Ecosystem*. San Francisco: Public Policy Institute of California. Available at www.ppic.org/main/publication.asp?i=1051.

Hanak, E., C. Phillips, J. Lund, J. Durand, J. Mount, and P. Moyle. 2013b. *Scientific and Stakeholder Views on the Delta Ecosystem*. San Francisco: Public Policy Institute of California. Available at www.ppic.org/main/publication.asp?i=1053.

Howitt, R., D. MacEwan, C. Garnache, J. Medellín-Azuara, P. Marchand, and D. Brown. 2012a. "Yolo Bypass Flood Date and Flow Volume Agricultural Impact Analysis." University of California, Davis, p. 60.

Howitt, R., J. Medellín-Azuara, D. MacEwan, and J. R. Lund. 2012b. "Calibrating Disaggregate Economic Models of Agricultural Production and Water Management." *Environmental Modeling & Software* 38: 244–58.

Jeffres, C. A., J. J. Opperman, and P. B. Moyle. 2008. "Ephemeral Floodplain Habitats Provide Best Growth Conditions for Juvenile Chinook Salmon in a California River." *Environmental Biology of Fishes* 83: 449–58.

Leung, B., D. Lodge, D. Finnoff, J. Shogren, M. A. Lewis, and G. Lamberti. 2002. "An Ounce of Prevention or a Pound of Cure: Bioeconomic Risk Analysis of Invasive Species." *Proceedings of the Royal Society of London* 269(1508): 2407–13.

Lindley, S. T., C. Grimes, M. S. Mohr, W. Peterson, J. Stein, J. T. Anderson, L. W. Botsford, D. L. Bottom, C. A. Busack, T. A. Collier, J. Ferguson, J. C. Garza, A. M. Grover, D. G. Hankin, R. G. Kope, P. W. Lawson, A. Low, R. B. MacFarlane, K. Moore, M. Palmer- Zwahlen, F. B. Schweig, J. Smith, C. Tracy, R. Webb, B. T. Wells, and T. H. Williams. 2009. "What Caused the Sacramento River Fall Chinook Stock Collapse?" Report to the Pacific Fishery Management Council.

Lodge, D. M. , S. Williams, H. MacIsaac, K. Hayes, B. Leung, L. Loope, S. Reichard, R. N. Mack, P. B. Moyle, M. Smith, D. A. Andow, J. T. Carlton, and A. McMichael. 2006. "Biological Invasions: Recommendations for Policy and Management (Position Paper for the Ecological Society of America)." *Ecological Applications* 16: 2034–54.

Lund, J., E. Hanak, W. Fleenor, W. Bennett, R. Howitt, J. Mount, and P. Moyle. 2010. *Comparing Futures for the Sacramento–San Joaquin Delta*. Berkeley: University of California Press.

Martineau, P. 2012. *The Next Decade in the Delta: Consensus on "Near-Term" Projects.* Association of California Water Agencies. Available at www.acwa.com/news/delta/next-decade-delta-consensus-near-term-projects.

Michael, J. 2010. "Employment Impacts of California Salmon Fishery Closures in 2008 and 2009." Eberhardt School of Business, University of the Pacific. Available at http://forecast.pacific.edu/BFC%20salmon%20jobs.pdf.

Medellín-Azuara, J. , E. Hanak, R. Howitt, and J. Lund. 2012. *Transitions for the Delta Economy*. San Francisco: Public Policy Institute of California. Available at www.ppic.org/main/publication.asp?i=913.

Medellín-Azuara, J., Rosenstock, T., Howitt, R., Harter, T., Jessoe, K., Dzurella, K., Pettygrove, S., and Lund, J. In press. "Agro-Economic Analysis of Nitrate Crop Source Reductions." *Journal of Water Resources Planning and Management* ISSN (online): 1943-5452. Available online at http://dx.doi.org/10.1061/(ASCE)WR.1943-5452.0000268.

Mount, J. 2011. "The Stockholm Syndrome in Water Planning in California." californiawaterblog.org. September 27.

Moyle, P.B. 2008. "The Future of Fish in Response to Large-scale Change in the San Francisco Estuary, California." In *Mitigating Impacts of Natural Hazards on Fishery Ecosystems. American Fishery Society, Symposium 64*, ed. K.D. McLaughlin. Bethesda, MD: American Fishery Society.

Moyle, P. B., and J. A. Israel. 2005. "Untested Assumptions: Effectiveness of Screening Diversions for Conservation of Fish Populations." *Fisheries* 30(5): 20–35.

Moyle P. B., P. K. Crain, and K. Whitener. 2007. "Patterns in the Use of a Restored California Floodplain by Native and Alien Fishes." *San Francisco Estuary and Watershed Science* 5(3): 1–27.

Moyle, P. B., and W. A. Bennett. 2008. "The Future of the Delta Ecosystem and Its Fish." Technical Appendix D, in *Comparing Futures for the Sacramento–San Joaquin Delta*. San Francisco: Public Policy Institute of California. Available at www.ppic.org/main/publication.asp?i=810.

Moyle, P. B., W. A. Bennett, W. E. Fleenor, and J.R. Lund. 2010. "Habitat Variability and Complexity in the Upper San Francisco Estuary." *San Francisco Estuary and Watershed Science* 8(3): 1–24.

Moyle, P. B., W. Bennett, J. Durand, W. Fleenor, B. Gray, E. Hanak, J. Lund, and J. Mount. 2012. *Where the Wild Things Aren't: Making the Delta a Better Place for Native Species.* San Francisco: Public Policy Institute of California. Available at www.ppic.org/main/publication.asp?i=1025.

Mount, J., W. Bennett, J. Durand, W. Fleenor, E. Hanak, J. Lund, and P. Moyle. 2012. *Aquatic Ecosystem Stressors in the Sacramento–San Joaquin Delta*. San Francisco: Public Policy Institute of California. Available at www.ppic.org/main/publication.asp?i=1024.

National Research Council. 2012. *Sustainable Water and Environmental Management in the California Bay-Delta*. Washington DC: National Academies Press.

Null, S. E., and J. R. Lund. 2006. "Reassembling Hetch Hetchy: Water Supply without O'Shaughnessy Dam." *Journal of the American Water Resources Association* 42(2): 395–408.

Paggi, M. S., J. E. Noel, and F. Yamazaki. 2009. "Model Applications Project, Regulatory Compliance Costs and California Specialty Crop Producers Profitability. " Final Report. Available at http://cab.cati.csufresno.edu/.

Parker, A. E., A. M. Marchi, J. Davidson-Drexel, R. C. Dugdale, and F. P. Wilkerson. 2010. "Effect of Ammonium and Wastewater Effluent on Riverine Phytoplankton in the Sacramento River, CA." Technical report for the State Water Resources Board.

Pejchar, L., and K. Warner. 2001. "A River Might Run Through It Again: Criteria for Consideration of Dam Removal and Interim Lessons from California." *Environmental Management* 28(5): 561–75.

Pires, S. F., and W. D. Moreto. 2011. "Preventing Wildlife Crimes: Solutions That Can Overcome the 'Tragedy of the Commons.'" *European Journal on Criminal Policy and Research* 17: 101–23.

Schoellhamer, D. H. 2011. "Sudden Clearing of Estuarine Waters upon Crossing the Threshold from Transport to Supply Regulation of Sediment Transport as an Erodible Sediment Pool Is Depleted: San Francisco Bay, 1999." *Estuaries and Coasts* 34: 885–99.

Sommer, T. R., W. C. Harrell, M. Nobriga, R. Brown, P. B. Moyle, W. J. Kimmerer, and L. Schemel. 2001. "California's Yolo Bypass: Evidence That Flood Control Can Be Compatible with Fish, Wetlands, Wildlife and Agriculture." *Fisheries* 58(2): 325–33.

State Water Resources Control Board. 2012. "Draft Appendix X: Agricultural Economic Effects of Lower San Joaquin River Flow Alternatives." Available at www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/water_quality_control_planning/.

Suddeth, R., J. Mount, and J. R. Lund. 2010. "Levee Decisions and Sustainability for the Sacramento–San Joaquin Delta." *San Francisco Estuary and Watershed Science* 8(2): 6.

Tanaka, S. K., C. Buck, K. Madani, J. Medellín-Azuara, J. Lund, and E. Hanak. 2011. "Economic Costs and Adaptations for Alternative Regulations of California's Sacramento–San Joaquin Delta," *San Francisco Estuary and Watershed Science*, 9(2): 28.

U.S. Environmental Protection Agency. 2009. *Drinking Water Infrastructure Needs Survey and Assessments.* Washington, DC.

Weston, D. P., and M. J. Lydy. 2010. "Urban and Agricultural Sources of Pyrethroid Insecticides to the Sacramento–San Joaquin Delta of California." *Environmental Science and Technology* 44: 1833–40.

Whipple, A., R. M. Grossinger, D. Rankin, B. Stanford, and R. Askevold. 2012. *Sacramento–San Joaquin Delta Historical Ecology Investigation: Exploring Pattern and Process*. Richmond, CA: San Francisco Estuary Institute.

Williams, J. G. 2006. "Central Valley Salmon: A Perspective on Chinook and Steelhead in the Central Valley of California." *San Francisco Estuary and Watershed Science* 4(3).

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