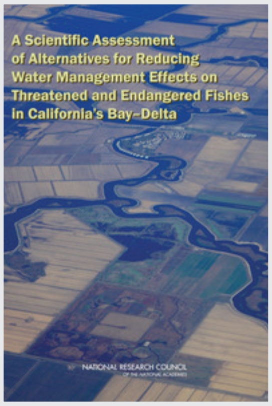

A Scientific Assessment of Alternatives for Reducing Water Management Effects on Threatened and Endangered Fishes in California's Bay-Delta (2010)

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Committee on Sustainable Water and Environmental Management in the California Bay-Delta

Water Science and Technology Board

Ocean Studies Board

Division on Earth and Life Studies

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Preface

California, like many states, faces challenges related to water. Much of the state is too dry to support many human activities, such as municipal and industrial water use and irrigated agriculture, without supplementing the natural water supply. It has done this through an extensive series of engineering projects that include reservoirs, canals, levees, and pumps, largely to move water from the more humid north to the more arid and densely populated south. Much of California's natural surface-water supply flows into and through the Sacramento and San Joaquin watersheds into California's Bay-Delta, and from there through San Francisco Bay into the ocean. The delta itself is a biologically diverse estuarine ecosystem, and is the main point of diversion for water that is transported to the south.

As California's population and economic activity have increased, along with water diversions from the delta, conflicts over various water uses have increased as well, especially surrounding the bay-delta. Those conflicts have been brought to a head by restrictions on water diversions that have been required by two biological opinions, one by the U.S. Fish and Wildlife Service, covering delta smelt, and one by the National Marine Fisheries Service, covering salmon, steelhead, and sturgeon, to protect those fishes, which are listed as threatened or endangered under the federal Endangered Species Act. In addition, several recent dry years have exacerbated the situation. Conflicts over water are not new in California, but the current conflicts over the bay-delta appear to be unprecedented in their scale. Few parts of the state are unaffected by what happens to delta water.

Protecting all the listed species and preserving existing and projected uses of the region's water is a serious challenge. The complexity of the problem and the difficulty of identifying solutions have been highlighted by a plethora of scientific publications and arguments, in which many qualified and distinguished experts have reached differing conclusions. Nobody disagrees that engineering changes; the introduction of many exotic species, the addition of contaminants to the system, and the general effects of an increasing human population have contributed to the fishes' declines. There are, however, disagreements about the relative contributions of those factors and the appropriate remedies for them. This is the context in which the National Research Council was asked by Congress and the Department of the Interior to help resolve the issue by evaluating the scientific bases of the biological opinions. In response, the NRC appointed a special committee of experts to carry out a complex and challenging study in two phases.

In its first phase, the committee was tasked to focus on the scientific bases of the reasonable and prudent alternatives (RPAs) in the two biological opinions. The committee also assessed whether the RPAs might be in conflict with one another, as well as whether other options might be available that would protect the fishes with lesser impacts on other water uses. Finally, we were asked to consider the effects of "other stressors" on the fishes if sufficient time were available. The results of this first-phase analysis are the subject of this report. The committee did consider other stressors, but it did not evaluate them in depth. They will be more thoroughly addressed in a second report, scheduled to be published late in 2011, which will focus on broader issues surrounding attempts to provide more sustainable water supplies and to improve the ecological sustainability of the delta, including consideration of what ecological goals might be attainable.

The committee met in Davis, California for five days in January 2010. The committee heard presentations from representatives of federal and state agencies and a variety of other experts, and from members of several stakeholder groups and the public (see Appendix D). The information gathering sessions of this meeting were open to the public and widely advertised. The committee sought to hear from as many groups and individuals as possible within the time constraints. All speakers, guests, and members of the public were encouraged to provide written comments during and after the meeting. All presentations and written materials submitted were considered by the committee as time allowed. The committee thanks all the individuals who provided information.

This report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise in accordance with the procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the NRC in making its published report as sound as possible, and to ensure that the report meets NRC institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

We thank the following for their reviews of this report: Joan G. Ehrenfeld, Rutgers University; Mary C. Fabrizio, Virginia Institute of Marine Science; Peter Gleick, Pacific Institute; William P. Horn, Birch, Horton, Bittner & Cherot;

D. Peter Loucks, Cornell University; Jay Lund, University of California, Davis; Tammy Newcomb, Michigan Department of Natural Resources; and Andrew A. Rosenberg, Conservation International.

Although these reviewers provided constructive comments and suggestions, they were not asked to endorse the report's conclusions and recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Michael Kavanaugh, Malcolm Pirnie, Inc., who was appointed by the NRC's Report Review Committee and by Leo Eisel, Brown and Caldwell, who was appointed by the NRC's Division on Earth and Life Studies. They were responsible for ensuring that an independent examination of this report was conducted in accordance with NRC institutional procedures and that all review comments received full consideration. Responsibility for this report's final contents rests entirely with the authoring committee and the NRC.

I am enormously grateful to my committee colleagues for their diligence, enthusiasm, persistence, and hard work. The schedule for the preparation of this report was short, and without everyone's engagement, it could not have been completed. I also am grateful to David Policansky, Stephen Parker, Laura Helsabeck, Heather Chiarello, Ellen de Guzman, and Susan Roberts of the NRC staff for their efforts in facilitating the committee's meeting and for their work in helping to get this report completed on schedule in the face of historic snowstorms.

California will continue to face great challenges in managing, allocating, and using water, including managing California's Bay-Delta. We hope the committee's reports can help in that difficult process.

Robert J. Huggett
Chair

Contents

Acronyms and Abbreviations

AF	Acre-feet
BA	Biological Assessment
BO	Biological Opinion
(C)DFG	California Department of Fish and Game
(C)DWR	California Department of Water Resources
C.F.R.	Code of Federal Regulations
Cir	Circuit Court (federal system)
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
DCC	Delta Cross Channel
DOI	(U.S.) Department of the Interior
DSM2	Delta Simulation Model II
EDT	Ecosystem Diagnosis and Treatment
ESA	Endangered Species Act
EWA	Environmental Water Account
FMT	Fall Midwater Trawl (survey)
FWS	(U.S.) Fish and Wildlife Service
HORB	Head of Old River Barrier
MAF	Million acre-feet
M&I	Municipal and Industrial
NAS	National Academy of Sciences
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
OCAP	Operations Criteria And Plan
OMR	Old and Middle River
OSB	Ocean Studies Board of the NRC
PTM	Particle-Tracking Model
RBDD	Red Bluff Diversion Dam
RPA	Reasonable and Prudent Alternative
SWP	State Water Project
TAF	Thousand acre-feet
USBR	United States Bureau of Reclamation
U.S.C.	United States Code
USGS	United States Geological Survey
VAMP	Vernalis Adaptive Management Plan
WSTB	Water Science and Technology Board of the NRC
X2	Contour line of salinity 2

Summary

California's Bay-Delta estuary is a biologically diverse estuarine ecosystem that plays a central role in the distribution of California's water from the state's wetter northern regions to its southern, arid, and populous cities and agricultural areas. In addition to its ecological functioning and the ecosystem services it provides, there are numerous withdrawals of freshwater from the delta, the largest being pumping stations that divert water into the federal Central Valley Project (CVP) and the State Water Project (SWP), primarily for agriculture and metropolitan areas. Most former wetland and marsh areas of the delta have been drained for agriculture, and are protected by an aging collection of levees. Some of those areas also contain small urban settlements.

This hydrologic and engineered system has met the diverse water-related needs of Californians for decades. But operation of the engineered system, along with the effects of an increasing population of humans and their activities, has substantially altered the ecosystem. These ecosystem changes have contributed to changes in the abundance, distribution, and composition of species in the delta, including the decline of many native species and the successful establishment of many species not native to the region.

Recently, the Fish and Wildlife Service (FWS) and the National Marine Fisheries Service (NMFS) issued biological opinions under the federal Endangered Species Act (ESA) that required changes ("reasonable and prudent alternatives," or RPAs) in water operations and related actions to avoid jeopardizing the continued existence and potential for recovery of delta smelt, winter-run and fall-run Chinook salmon, Central Valley steelhead, and green sturgeon. Those changes have reduced the amount of water available for other uses, and the tensions that resulted have been exacerbated by recent dry years.

The RPAs are divided into many separate actions. The RPA in the FWS opinion, divided into six actions, applies to delta smelt and thus focuses primarily on managing flow regimes to reduce entrainment of smelt and on extent of suitable water conditions in the delta, as well as on construction or restoration of

habitat. The NMFS RPA, divided into five actions with a total of 72 subsidiary actions, applies to the requirements of Chinook salmon, steelhead, and green sturgeon in the delta and farther upstream. In addition to its focus on flow regimes and passage, it includes purchasing water to enhance in-stream flow, habitat restoration, a new study of acoustic-tagged steelhead, and development of hatchery genetics management plans. This committee did not evaluate all 78 actions and subsidiary actions in the two RPAs in detail. It spent most of its time on the elements of the RPAs that have the greatest potential to affect water diversions. It also spent time on elements whose scientific justifications appear to raise some questions.

Protecting all the listed species, as required by the ESA, while simultaneously trying to minimize impacts on existing and projected uses of the region's water, is a serious challenge. In addition, many anthropogenic and other factors, including pollutants; introduced species; and engineered structures such as dams, canals, levees, gates, and pumps adversely affect the fishes in the region, but they are not under the direct control of the CVP or the SWP, and thus are not subjects of the biological opinions.

The complexity of the problem of the decline of the listed species and the difficulty of identifying viable solutions have led to disagreements, including concerns that some of the actions in the RPAs might be ineffective and might cause harm and economic disruptions to water users, and that some of the actions specified in the RPAs to help one or more of the listed species might harm others. In addition, some have suggested that the agencies might be able to meet their legal obligation to protect species with less economic disruptions to other water users. Those concerns led the Department of the Interior and Congress to ask for advice from the National Research Council (NRC), which appointed a special committee of experts to carry out this study.

THE COMMITTEE'S CHARGE

The committee's charge includes the following tasks (the full statement of task is in Appendix A).

The committee was asked to undertake two main projects over a term of two years resulting in two reports. The first report, prepared on a very short timeline, was to address scientific questions, assumptions, and conclusions underlying water-management alternatives (i.e., the RPAs) in the two biological opinions mentioned above, and this is where the committee focused most of its attention. In addition, three specific issues were to be addressed. First, are there any "reasonable and prudent alternatives" (RPAs) that, based on the best available scientific data and analysis, would provide equal or greater protection for the listed species and their habitat while having lesser impacts to other water uses than those adopted in the biological opinions? Second, are there provisions in the biological opinions to resolve the potential for actions that would benefit one listed species while causing negative impacts on another? And finally, to the extent that time permits, the committee was asked to consider the effects of other stressors (e.g., pesticides, ammonia discharges, invasive species) on federally listed and other at-risk species in the Bay-Delta. The committee's second report, due in late 2011, will address how to most effectively incorporate science and adaptive management concepts into holistic programs for management and restoration of the Bay-Delta.

The committee's charge was to provide a scientific evaluation, not a legal one, and that is what the committee did. **Nothing in this report should be interpreted as a legal judgment as to whether the agencies have met their legal requirements under the ESA.** The committee's report is intended to provide a scientific evaluation of agency actions, to help refine them, and to help the general attempt to better understand the dynamics of the delta ecosystem, including the listed fishes.

THE COMMITTEE'S PRINCIPAL CONCLUSIONS

Context

The California Bay-Delta is a system that has undergone significant anthropogenic changes for more than a century. Those changes include water withdrawals; draining of wetlands; introduction of many nonnative species of plants and animals, some deliberate; construction of canals, gates, marinas, roads, levees, pumps, dams, and other structures that affect the hydrology of the system; the damming of almost all the major rivers and tributaries to the system, which also has altered the seasonal flow regime and other hydrologic aspects of the system; and the release of contaminants, pollutants, and nutrients into the system as a result of the above changes and the increase of agriculture, industrial and residential development, and other human activities. All these changes have affected the distribution, abundance, and composition of species in the delta, some of which have increased dramatically and some, including the species listed under the Endangered Species Act (Chinook salmon, delta smelt, steelhead, and green sturgeon), which have declined precipitously. The biological opinions with their associated RPAs that the committee has reviewed relate only to proposed changes in operations of the CVP and the SWP in the delta and methods to reduce the adverse effects on the listed species of those changes. Some restrictions on CVP and SWP water diversions have been initiated to protect the listed fish species, but so far have not produced measurable effects in slowing their declines.

The committee concludes that reversing or even slowing the declines of the listed species cannot be accomplished immediately. Even the best-targeted methods of reversing the fish declines will need time to take effect amid changing environmental conditions such as multi-year droughts and continued pressures on the system from other human-caused stresses. Especially for fishes whose populations are very low already, the effects of any actions will be difficult to detect at first, and detecting them will be made more difficult by the effects of other environmental changes and uncertainties inherent in sampling small populations.

The FWS Biological Opinion and RPA

The committee considered the six actions contained within the RPA, most of which were judged to have a sound conceptual basis. The committee then focused on the RPA actions that involved Old and Middle River (OMR) flows, the management of the mean position of the contour where salinity is 2[1] (X2), and the creation or restoration of tidal habitat for smelt. The first two actions involve significant requirements for water; the third does not.

The management of OMR flows is predicated on the concept that pumping of water for export from the south delta creates net negative (toward the pumps) flows, averaged over the tidal cycle, that cause delta smelt (and some juvenile salmon) to be experience increased mortality in the south delta, especially in winter. The RPA action limits the net OMR flows to levels that depend on conditions during this period, with a variety of environmental triggers and adaptive-management procedures. **Although there are scientifically based arguments that raise legitimate questions about this action, the committee concludes that until better monitoring data and comprehensive life-cycle models are available, it is scientifically reasonable to conclude that high negative OMR flows in winter probably adversely affect smelt populations. Thus, the concept of reducing OMR negative flows to reduce mortality of smelt at the SWP and CVP facilities is scientifically justified.**

[1] This is often expressed as a concentration, e.g., "2 parts per thousand," but more recently it has been expressed as a ratio of electrical conductivities, hence it has no units.

However, there is substantial uncertainty regarding the amount of flow that should trigger a reduction in exports. In other words, the specific choice of the negative flow threshold for initiating the RPA is less clearly supported by scientific analyses. The biological benefits and the water requirements of this action are likely to be sensitive to the precise values of trigger and threshold values. There clearly is a relationship between negative OMR flows and mortality of smelt at the pumps, but the data do not permit a confident identification of the threshold values to use in the action, and they do not permit a confident assessment of the benefits to the population of the action. As a result, the implementation of this action needs to be accompanied by careful monitoring, adaptive management, and additional analyses that permit regular review and adjustment of strategies as knowledge improves.

The management of the mean position of X2 during the fall (Action 4 of the FWS RPA) is based on observations that relate smelt use of spawning habitat with various salinity regimes. X2 is interpreted by the agencies not as a single line, but rather as an indicator of the spatial pattern of salinity in the delta and thus as indicative of the extent of habitat favorable for delta smelt.

The relationships among smelt abundance, habitat extent, and the mean position of X2 as an indicator of available habitat are complex. The controversy about the action arises from the poor and sometimes confounding relationship between indirect measures of delta smelt populations (indices) and X2. Although there is evidence that the position of X2 affects the distribution of smelt, the weak statistical relationship between the location of X2 and the size of smelt populations makes the justification for this action difficult to understand. In addition, although the position of X2 is correlated with the distribution of salinity and turbidity regimes, the relationship of that distribution and smelt abundance indices is unclear. **The X2 action is conceptually sound in that to the degree that the amount of habitat available for smelt limits their abundance, the provision of more or better habitat would be helpful. However, the derivation of the details of this action lacks rigor.** The action is based on a series of linked statistical analyses (e.g., the relationship of presence/absence data to environmental variables, the relationship of environmental variables to habitat, the relationship of habitat to X2, the relationship of X2 to smelt abundance). Each step of this logical train of relationships is uncertain. The relationships are correlative with substantial variance left unexplained at each step, yet the analyses do not carry the uncertainty at each step to the next step. The action also may have high water requirements and may adversely affect salmon and steelhead under some conditions. **As a result, the committee concludes that how specific X2 targets were chosen and their likely beneficial effects need further clarification. It also is critical that the adaptive-management requirements**

included in the RPA be implemented in light of the uncertainty about the biological effectiveness of the action and its possibly high water requirements.

The tidal habitat management action in the RPA requires creation or restoration of 8,000 acres of intertidal and subtidal habitat in the delta and in Suisun Marsh. This action has not been controversial because it does not affect other water users. **The committee finds that the conceptual foundation for this action (Action 6) is weak because the relationship between tidal habitats and food availability for smelt is poorly understood. The details of its implementation are not fully justified in the biological opinion. The committee recommends that this action be implemented in phases, with the first phase to include the development of an implementation and adaptive management plan (similar to the approach used for the floodplain habitat action in the NMFS biological opinion), but also to explicitly consider the sustainability of the resulting habitats, especially those dependent on emergent vegetation, in the face of expected sea-level rise.** In addition, there should be consideration of the types and amounts of tidal habitats necessary to produce the expected outcomes and how they can be achieved and sustained in the long term. The committee supports the monitoring program referred to in Action 6, and appropriate adaptive management triggers and actions.

The NMFS Biological Opinion and RPA

The NMFS RPA for salmon, steelhead, and green sturgeon is a broad complex of diverse actions spanning three habitat realms: tributary watersheds, the mainstem Sacramento and San Joaquin Rivers, and the delta. **On balance, the committee concludes that the actions, which are primarily crafted to improve life-stage-specific survival rates for salmon and steelhead, with the recognition that the benefits also will accrue to sturgeon, are scientifically justified.** The strategies underpinning many of the individual actions are generally well supported by more than a decade of conceptual model building about the requirements of salmonids in the region, although the extent to which the intended responses are likely to be realized is not always clearly addressed in the RPA. Given the absence of a transparent, quantitative framework for analyzing the effects of individual and collective actions, it is difficult to make definitive statements regarding the merits of such a complex RPA. Indeed, absent such an analysis, the controversial aspects of some of the RPA actions could detract from the merits of the rest of the RPA.

In general, as described in detail in Chapter 6, the committee concludes that although most, if not all, of the actions in this RPA had a sound conceptual basis, the biological benefits and water requirements of several of the actions are, as with the delta smelt actions, likely quite sensitive to the specific triggers, thresholds, and flows specified. As a result, the committee recommends that the specific triggers, thresholds, and flows receive additional evaluation that is integrated with the analyses of similar actions for delta smelt.

In particular, the committee concludes that it is difficult to ascertain to what extent the collective watershed and tributary actions will appreciably improve survival within the watershed or throughout the entire river system. The committee concludes that the actions to improve mainstem passage for salmonids and sturgeon, in particular those concerning the Red Bluff Diversion Dam, are well justified scientifically. The committee recommends some kind of quantitative assessment framework for assessing survival be developed and implemented.

The management of OMR flows to reduce entrainment mortality of salmon smolts is similar in concept to the smelt OMR action, and like that action, **the committee concludes that its conceptual basis is scientifically justified, but the scientific support for specific flow targets is less certain. Uncertainty in the effect of the triggers should be reduced, and more-flexible triggers that might require less water should be evaluated.**

Another set of actions in this RPA focuses on managing exports and flows in the San Joaquin River to benefit outmigrating steelhead smolts. The actions are intended to reduce the smolts' vulnerability to entrainment into the channels of the south delta and the pumps by increasing the inflow-to-export ratio of water in the San Joaquin River. It thus has two components: reducing exports and increasing San Joaquin River inflows into the delta. **The committee concludes that the rationale for increasing San Joaquin River flows has a stronger foundation than does the prescribed export action. We further conclude that the action involving a six-year study of smolt survival would provide useful insight into the effectiveness of the actions as a long-term solution.**

The final two actions considered here were improving the migratory passage of salmon and sturgeon through the Yolo Bypass and the inundation of additional floodplain lands to provide additional rearing habitat for juvenile salmon. **The committee concludes that both actions are scientifically justified, but the implications for the system as a whole of routing additional flows through the Yolo Bypass for the system were not clearly analyzed.** In particular, the consequences of the action for Sacramento River flows and for the potential mobilization of mercury were not clearly described.

Other Possible RPAs

The committee's charge requires the identification, if possible, of additional potential RPAs that might have the potential to provide equal or greater protection to the fishes than the current RPAs while costing less in terms of water availability for other uses. **The committee considered a variety of possible actions not in the RPAs (see Chapter 6), and concluded that none of them had received sufficient documentation or evaluation to be confident at present that any of them would have the potential to provide equal or greater protections for the species while requiring less disruption of delta water diversions.**

Other Stressors

Based on the evidence the committee has reviewed, the committee agreed that the adverse effects of all the other stressors on the listed fishes are potentially large. Time did not permit full exploration of the issue in this first report, but examples of how such stressors may affect the fishes are described. The committee will explore this issue more thoroughly in its second report.

Modeling

The committee reviewed the models the agencies used to understand the basis for the resource agencies' jeopardy opinion and to determine to what degree they used the models in developing the RPAs. **The committee concluded that as far as they went, despite flaws, the individual models were scientifically justified, but that they needed improvements and that they did not go far enough toward an integrated analysis of the RPAs. Thus the committee concluded that improving the models by making them more realistic and by better matching the scale of their outputs to the scale of the actions, and by extending the modeling framework to be more comprehensive and to include features such as fish life cycles would improve the agencies' abilities to assess risks to the fishes, to fine-tune various actions, and to predict the effects of the actions.**

Potential Conflicts Between RPAs and Integration of RPAs

The committee concludes that the RPAs lack an integrated quantitative analytical framework that ties the various actions together within species, between smelt and salmonid species, and across the watershed. This type of systematic, formalized analysis, although likely beyond the two agencies' legal obligations when rendering two separate biological opinions, is necessary to provide an objective determination of the net effect of all their actions on the listed species and on water users.

An additional overall, systematic, coordinated analysis of the effect of all actions taken together and a process for implementing the optimized, combined set of actions is required to establish the credibility of the effort overall. The committee is aware that instances of coordination among the agencies certainly exist, including modification of actions to reduce or eliminate conflicting effects on the species. Indeed, the committee did not find any clear example of an action in one of the RPAs causing significant harm to the species covered in the other RPA. But coordination is not integration. The lack of a systematic, well-framed overall analysis is a serious scientific deficiency, and it likely is related to the ESA's practical limitations as to the scope of actions that can or must be considered in a single biological opinion. The interagency effort to clearly reach consensus on implications of the combined RPAs for their effects on all the species and on water quality and quantity within the delta and on water operations and deliveries should use scientific principles and methods in a collaborative and integrative manner. Similarly, this committee's efforts to evaluate potential harmful effects of each RPA on the species covered in the other RPA were hampered by the lack of a systematic, integrated analysis covering all the species together. Full documentation of decisions should be part of such an effort, as should inclusion of the environmental water needs of specific actions and for the entire RPA.

It is clear that integrative tools that, for example, combine the effect over life stages into a population-level response would greatly help the development and evaluation of the combined actions. There has been significant investment in hydrological and hydrodynamic models for the system, which have been invaluable for understanding and managing the system. An investment in ecological models that complement and are integrated with the hydrological and hydrodynamics models is sorely needed. Clear and well-documented consideration of water requirements also would seem well advised because some of the actions have significant water requirements. Credible documentation of the water needed to implement each action and the combined actions, would enable an even clearer and more logical formulation of how the suite of actions might be coordinated to simultaneously benefit the species and ensure water efficiency. **This recommendation for integration of models and across species responds to the committee's broad charge of advising on how to most effectively incorporate scientific and adaptive-management concepts into holistic programs for managing the delta, and likely goes beyond the agencies' legal obligations under the ESA, and will be addressed more thoroughly in the committee's second report.**

1
Introduction

California's Bay-Delta estuary is a biologically diverse estuarine ecosystem that plays a central role in the distribution of California's water from the state's wetter northern regions to its southern, arid, and populous cities and agricultural areas (Figure 1-1). The Bay-Delta region receives water flows from the Sacramento and San Joaquin Rivers and their tributaries, which drain the east slopes of the Coast Range, the Trinity Alps and Trinity Mountains in northern California, and the west slopes of the Sierra Nevada Mountains. Outflows from the Bay-Delta, through San Francisco Bay and into the Pacific Ocean, are met by tidal inflows, resulting in a brackish water ecosystem in many reaches of the Bay-Delta. In addition to its ecological functioning and the ecosystem services it provides, there are numerous withdrawals of freshwater from the Bay-Delta, the largest being pumping stations that divert water into the federal Central Valley Project (CVP), primarily for Central Valley agriculture, and the State Water Project (SWP), primarily for southern California metropolitan areas. Other water is extracted from Bay-Delta waterways for consumptive use within the delta region itself, and for municipal and industrial use around the margins of the delta, and returned to its waterways diminished in quantity and quality. Most former wetland and marsh areas of the delta have been drained for agriculture, and are protected by an aging collection of levees (Moyle et al., 2010). Some of those areas also contain small urban settlements.

This hydrologic and engineered system has met the diverse water-related needs of Californians for decades. But construction and operation of the engineered system, along with the effects of an increasing population of humans and their activities, have substantially altered the ecosystem. Current conditions include altered water-quality and salinity regimes and the magnitude and direction of flows in the delta, with rigorous management of the location of the contour where salinity is 2[1] (known as X2) through flow releases from upstream reservoirs. Consequent changes in the abundance, distribution, and composition of species in the delta have been compounded by the introduction and invasion

[1] This is often expressed as a concentration, e.g., “2 parts per thousand,” but more recently it has been expressed as a ratio of electrical conductivities, hence it has no units.

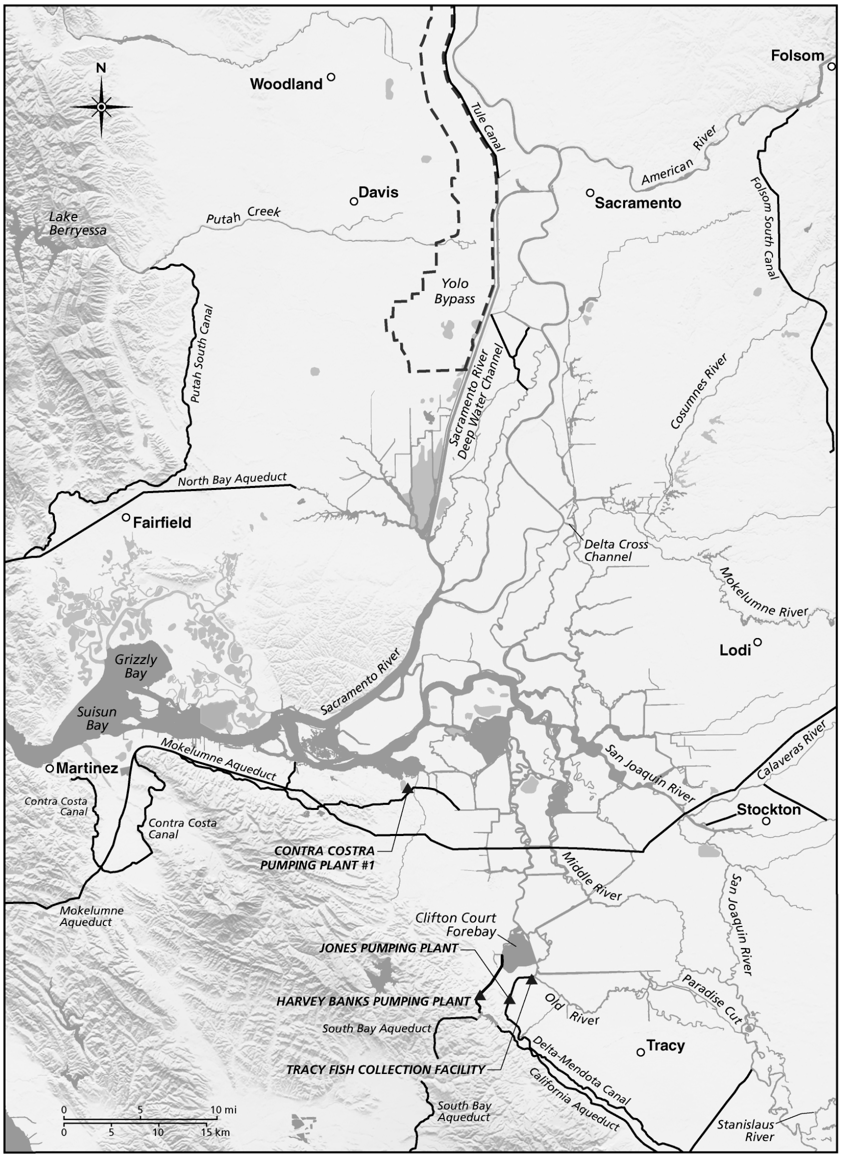

FIGURE 1-1 Map of the delta. SOURCE: Modified from FWS (2008).

of many species not native to the region.

Recently, several species of native fishes have been listed as threatened or endangered under the federal Endangered Species Act (ESA) and the California Endangered Species Act. This study focuses only on the federal ESA. The federal listings have led to Section 7 (of the ESA) consultations between the operators of the CVP (the U.S. Bureau of Reclamation, or USBR) and of the SWP (the California Department of Water Resources, or DWR) and the Fish and Wildlife Service (FWS), the National Marine Fisheries Service (NMFS), and the California Department of Fish and Game (DFG). Those consultations led to the issuance of opinions by the Services that required changes ("reasonable and prudent alternatives," or RPAs) in water operations and related actions to avoid jeopardizing the continued existence and potential for recovery of delta smelt (*Hypomesus transpacificus*), winter-run and fall-run Chinook salmon (*Oncorhynchus tshawytscha*), Central Valley steelhead (*Oncorhynchus mykiss*), and green sturgeon (*Acipenser medirostris*). The impacts of the RPAs on water users and the tensions that resulted have been exacerbated recently by series of dry years. In the longer term, climate change presents uncertainties and challenges with its anticipated impact on precipitation, snowpack, streamflow, and rising sea level, which will affect not only salinity and riparian habitats in the delta but likely also will threaten the integrity of the extensive system of levees (1,100 miles in length).

The RPAs are divided into many separate actions. The RPA in the FWS opinion (FWS, 2008), divided into six actions, focuses primarily on the flow and storage regimes as affected by diversions (pumping water to the south) and on reducing entrainment, with some focus on habitat. The NMFS RPA (NMFS, 2009) is divided into five actions with a total of 72 subsidiary actions. In addition to its focus on flow regimes, storage, and passage, it includes purchasing water to enhance in-stream flow, habitat restoration, a new study of acoustic-tagged steelhead, and development of hatchery genetics management plans. This committee did not evaluate all 78 actions and subsidiary actions in the two RPAs in detail. It spent most of its time on the elements of the RPAs that have the greatest potential to affect water diversions. It also spent time on elements whose scientific justifications appear to raise some questions.

Protecting all the listed species and preserving existing and projected uses of the region's water is a serious challenge. As the NMFS biological opinion (NMFS, 2009) says, "the current status of the affected species is precarious," and "it has been difficult to formulate an RPA that is likely to avoid jeopardy to all listed species and meets all regulatory requirements." Adding to this difficulty is the existence of the many anthropogenic and other factors that adversely affect the fishes in the region but which are not under the direct control of the

CVP or the SWP, and thus are not subjects of the biological opinions[2]. These include other human modifications to the system, including pollutants; invasive species and altered species composition; and engineered structures such as dams, canals, gates, pumps, and levees.

The complexity of the problem of the decline of the listed species and the difficulty of identifying solutions to it have led to disagreements, including concerns that some of the actions in the RPAs might cause harm and economic disruptions to many water users, and that some of the actions specified in the RPAs to help one or more of the listed species might harm others.

SYSTEM OVERVIEW

Overview of System Hydrology

We briefly describe the Sacramento-San Joaquin delta (Figure 1-1) and the two massive water storage and delivery projects that affect the area. Several publications go into great detail describing the delta and the operations of the federal and state water systems (DWR, 2006, 2009a, 2009b; USBR, 2006).

The Central Valley Project (CVP) operated by the U.S. Bureau of Reclamation and the State Water Project operated by the California Department of Water Resources provide water to farms and cities in an area encompassing the majority of the land and population of California. The two projects constitute the largest agriculture and municipal water-supply system in the United States. Water supplying both projects ultimately comes mainly from California's two major river systems—the Sacramento and the San Joaquin—with substantial imports from the Trinity River. Water also is stored in several major reservoirs as well, including Shasta (capacity 4.6 million acre-feet[3], or MAF), Oroville (3.4 MAF), Trinity (2.4 MAF), New Melones (2.4 MAF), San Luis (2 MAF), Don Pedro (2 MAF), McClure (Exchequer) (1 MAF), and Folsom (1 MAF), as well as many smaller ones. Releases from those reservoirs are used to help manage flows and salinity in the delta, as well as being used for agriculture, municipal and industrial uses, recreation, flood protection, and hydropower.

The CVP provides about 5 MAF of water to agriculture each year (about 70 percent of the CVP's supply), 0.6 MAF for municipal and industrial (M&I) use

[2] Those other mainly adverse changes are considered as part of the "environmental baseline."

[3] An acre-foot is the amount of water required to cover an acre of land to a depth of one foot; it is equal to 43,560 cubic feet, 325,851 gallons, or 1,234 cubic meters of water.

(serving about 2 million people) and 1.4 MAF to sustain fish, wildlife, and their habitats. The SWP provides about 70 percent of its water to M&I customers (about 20 million people) and 30 percent to agriculture (about 660,000 acres of irrigated farmland). The largest SWP contractor is the Metropolitan Water District of Southern California, which receives about 50 percent of SWP deliveries in any one year. At least two-thirds of the population of California depends on water delivered from these projects as a primary or supplemental source of supply. Other important functions provided by both projects include flood protection, recreation, power generation, and water quality to preserve fish and wildlife.

Both projects preceded and accommodated the explosive growth of California's economy and population. The CVP was begun in the mid to late 1930s and the SWP was begun in the 1960s. Dozens of reservoirs and lakes, pumping facilities, and over 1,200 miles of pipelines and canals make up the two interdependent water-supply and delivery systems.

The Sacramento-San Joaquin Delta

In the middle of both systems and connecting the northern water supply reservoirs and southern water demands is the Sacramento-San Joaquin Delta (Figure 1-1). Thus, the delta is an integral part of the water-delivery infrastructure for both the SWP and CVP. While the focus of this report is the determination of the effects of water allocations for fish, there are many other requirements that must be met in the delta to maintain flows and quality for the many uses of water delivered by the SWP and CVP projects.

Two major pumping plants draw water from the channels and rivers feeding the delta. The SWP pumping plant (Banks Pumping Plant) can deliver an average flow of nearly 6,700 cubic feet per second (cfs) to Clifton Court Forebay for transport to users south of the delta. The Jones Pumping Plant withdraws water primarily from Old River and has the capability of 4,600 cfs to contractors in southern California. Relatively small amounts of water are extracted for the Contra Costa canal (up to 195,000 af or 195 thousand acre-feet {TAF} per year) and the North Bay Aqueduct (up to 71 TAF per year) (FWS, 2008). In addition, diversions occur upstream of the delta. These diversions affect the location of X2, the amount of water that can be withdrawn at the pumps, the flow in the San Joaquin River, and other factors.

THE PRESENT STUDY

The statement of task (Appendix A) charges the NRC committee to review the scientific basis of the Services' RPAs and advise on how to most effectively incorporate science and adaptive management concepts into holistic programs for management and restoration of the delta. To balance the need to inform near-term decisions with the need for an integrated view of water and environmental management challenges over the longer-term, the committee was tasked to produce two reports. This first report focuses on the scientific bases of the water-management alternatives (RPAs) in the two biological opinions and whether there might be possible alternative RPAs that would be as or more protective of the fishes with lesser impacts on other water uses. The committee also has considered "other stressors," as specified in its statement of task. These are stressors not necessarily directly associated with the water projects; they are part of the "environmental baseline," a concept related to the Endangered Species Act that refers to other anthropogenic modifications of the environment. As such, they are not addressed by the RPAs, because RPAs must address operations of the water projects.

In this first report, most of the committee's focus has been on the question of the scientific bases of the water-management alternatives (RPAs) in the biological opinions, with a smaller focus on potential conflicts between the RPAs, potential alternative RPAs, and other stressors. The committee's second report will focus on broader issues surrounding attempts to provide more sustainable water supplies and to improve the ecological sustainability of the delta, including consideration of what ecological goals might be attainable.

To prepare this report, the committee met in Davis, California for five days in January 2010. It heard presentations from representatives of federal and state agencies and a variety of other experts, and from members of the public, and began work on the report. The committee was able to consider information received by February 8, 2010. Additional writing and two teleconferences occurred in February, and the report was reviewed according to the NRC's report-review procedure (the reviewers are acknowledged in the preface).

2

The Legal Context of This Report

SCOPE OF THE COMMITTEE'S TASK

The committee was asked "to review the scientific basis of actions that have been and could be taken to simultaneously achieve both an environmentally sustainable Bay-Delta and a reliable water supply." While this committee's review is scientific, and not legal, the committee nonetheless recognizes the importance of the legal context within which its evaluation takes place. The standard of review applicable in legal challenges to the opinions and associated RPAs provides a useful reference. In such lawsuits, courts will invalidate the RPAs only if they are demonstrated to be "arbitrary, capricious, an abuse of discretion, or otherwise not in accordance with law" (Administrative Procedure Act, 5 U.S.C. § 706(2)(A)). Courts are reluctant to second-guess technical agency judgments and may not substitute their judgment for that of the agency, particularly in cases where there are scientific uncertainty and differing scientific views. *See* Aluminum Co. of America v. Bonneville Power Administration, 175 F.3d 1156 (9th Cir. 1999); Trout Unlimited v. Lohn, 559 F.3d 946 (9th Cir. 2009). Thus, while the committee can come to different conclusions than the agencies did in their biological opinions, that would not be a *legal* justification for deeming them inadequate, as long as the agencies adequately considered the available scientific data and their conclusions are supportable by the evidence. Similarly, the RPAs should not be considered *legally* inadequate simply because different alternatives could be scientifically justified, as long as the agencies could reasonably believe that their RPAs would avoid the likelihood of jeopardy.

Some aspects of the committee's task require it to make determinations beyond the scope of the agencies' legal obligations or authority when issuing a biological opinion and RPAs. For example, the committee's charge includes consideration of the effects of stressors such as pesticides, ammonium, and invasive species on federally listed and other at-risk species in the Bay-Delta—stressors likely beyond the action agencies' legal authority to regulate, unless the effects are indirectly changed by the RPAs. Any such considerations by this committee in this or in its second report would have no bearing on the question of whether or not the biological opinions and RPAs are legally adequate. Instead, such considerations should be interpreted in contexts apart from the biological opinion and RPAs, such as the Bay-Delta Conservation Program (development of a habitat conservation plan); the State Water Resources Control Board's development of flow criteria for the delta; the Delta Stewardship Council's development of a delta plan; and others.

POTENTIAL VIOLATIONS OF ESA SECTION 7 AND SECTION 9

In each biological opinion, the relevant wildlife agency concluded that the proposed federal action—implementation of the water projects' operations plan—was likely to "jeopardize" the continued existence of species listed as endangered and to adversely modify their critical habitat. This would violate Section 7 of the Endangered Species Act (ESA), which requires agencies to "insure" that any actions they authorize, fund, or carry out are not likely to jeopardize endangered species or to destroy or adversely modify the species' critical habitat (16 U.S.C. § 1536 (a) (2)). As defined by agency regulations, "jeopardy" means that the proposed action "reasonably would be expected, directly or indirectly, to reduce appreciably the likelihood of both the survival and recovery of [relevant endangered species] in the wild by reducing the reproduction, numbers, or distribution of that species" (50 C.F.R. § 402.02). As required by the ESA, the wildlife agencies suggested "reasonable and prudent alternatives" (RPAs) that would allow the action to go forward without violating Section 7 (16 U.S.C. § 1536 (B) (3) (A)).

In addition to the jeopardy determinations (generally, applying to species as a whole), both biological opinions found that the proposed action would "take" individual members of the endangered populations in violation of Section 9 of the ESA. By regulation, the "take" of an endangered species includes "an act which actually kills or injures wildlife" and may include "significant habitat modification or degradation where it actually kills or injures wildlife by significantly impairing essential behavioral patterns, including breeding, feeding, or sheltering" (Babbitt v. Sweet Home Chapter of Communities, 515 U.S. 687 (1995)).

The resource agencies, the National Marine Fisheries Service and the Fish and Wildlife Service, issued an "incidental take statement," in the present case, setting forth reasonable and prudent measures necessary and appropriate to minimize the effect of the proposed action on endangered species. If the action agencies (the Bureau of Reclamation and the California Department of Water

Resources) comply with those measures, including monitoring and reporting requirements, then any "takes" that result from project operations will be deemed "incidental," and they will be exempt from the prohibitions of Section 9.

STANDARDS FOR THE PREPARATION OF BIOLOGICAL OPINIONS

Best Available Data

Under the ESA, the agencies must develop their biological opinions and associated RPAs using the "best scientific and commercial data available" (16 U.S.C. § 1536 (a) (2)). Courts have emphasized the qualifier *available,* explaining that perfect data are not required. Action can be taken based on imperfect data, so long as the data are the best available. In addition, the above requirement does not remove the agency's discretion to rely on the reasonable judgments of its own qualified experts, even if others, even a court, might find alternative views more persuasive (see Aluminum Co. v. Bonneville Power Admin., 175 F.3d 1156 (9th Cir. 1999).

Thus, the courts afford the agencies significant deference in determining the best data available for developing the RPAs. Therefore, even if this committee might have relied on different data or come to different conclusions than the agencies did, it does not follow that the RPAs are legally insufficient. Rather, this committee's conclusions and recommendations should be seen as applying to future work beyond the scope of the agencies' legal obligations.

Economic Considerations

Although the economic impact of species protections may be relevant under the ESA, its influence is limited. For example, economic concerns *may not* be part of the decision whether or not to list species as endangered or threatened, but *must be* considered when the agencies designate critical habitat (16 U.S.C. § 1533). When developing biological opinions and RPAs, the Ninth Circuit acknowledged that the wildlife agencies may go beyond "apolitical considerations" and that if two proposed RPAs would avoid jeopardy to the relevant species, the agencies "must be permitted to choose the one that best suits all of its interests, including political or business interests." Southwest Center for Biological Diversity v. U.S. Bureau of Reclamation, 143 F.3d 515 (9th Cir. 1998); *See also* Bennett v. Spear, 520 U.S. 154 (1997) (asserting that the "best scientific and commercial data" provision is . . . intended, at least in part, to prevent uneconomic [because erroneous] jeopardy determinations"). Nevertheless, the lower courts have been reluctant to second-guess agency opinions on the basis of economic arguments (Aluminum Co. cited above).

Effects of the Proposed Action and the Environmental Baseline

In preparing biological opinions, agencies must evaluate the "effects of the [proposed] action" on the species or its critical habitat. Other adverse modifications of the species' habitats or negative effects on their populations are considered part of the "environmental baseline." The agencies' analysis includes consideration of:

1) direct effects;
2) indirect effects ("those that are caused by the proposed action and are later in time, but still are reasonably certain to occur");
3) interrelated actions ("those that are part of a larger action and depend on the larger action for their justification");
4) interdependent actions ("those that have no independent utility apart from the action under consideration"); and
5) cumulative effects ("those effects of future State or private activities, not involving Federal activities, that are reasonably certain to occur within the action area of the Federal action subject to consultation") (50 C.F.R. §§ 402.02 and 402.14(g)(3-4)).

STANDARDS FOR THE PREPARATION OF REASONABLE AND PRUDENT ALTERNATIVES (RPAs)

Although RPAs are not binding on the action agency, adherence to the RPAs provides the agency with a safe harbor from claimed violations of the ESA. As the U.S. Supreme Court explained, "the action agency is technically free to disregard the Biological Opinion and proceed with its proposed action, but it does so at its own peril (and that of its employees), for 'any person' who knowingly 'takes' an endangered or threatened species is subject to substantial civil and criminal penalties, including imprisonment" (Bennett v. Spear, 520 U.S. 154 (1997)).

Under agency regulations, the RPAs must satisfy each of the following four requirements:

1) Project purpose: RPAs must be capable of implementation in a manner consistent with the intended purpose of the action.
2) Scope of agency authority: RPAs must be consistent with the scope of the action agencies' legal authority and jurisdiction.
3) Feasibility: RPAs must be economically and technologically feasible; and
4) Avoid jeopardy: The directors of FWS and NMFS must believe that the RPAs would avoid the likelihood of jeopardizing the continued existence of listed species or resulting in the destruction or adverse modification of critical habitat (50 C.F.R. § 402.02).

Although RPAs must avoid the likelihood of jeopardy, they are not required to promote recovery of the affected species. In other words, no RPA has the responsibility of mitigating all the adverse effects—the "environmental baseline"—that may be causing the decline of a listed species. They must only avoid the likelihood that the *proposed action* will cause jeopardy.

3

The Life Histories of the Fishes

INTRODUCTION

Chinook salmon (*Oncorhynchus tshawytscha*), steelhead (*Oncorhynchus mykiss*), and green sturgeon (*Acipenser medirostris*) are anadromous species; that is, they spawn in freshwater but spend a portion of their life in saltwater. Delta smelt (*Hypomesus transpacificus*) are resident within the brackish and freshwater habitats of the delta. In both anadromous and resident life-history strategies the fish migrate from their natal habitat into their adult habitat and then back to the spawning habitat, completing the life cycle. The fish do not simply drift between their habitats, but have evolved specific life-stage behaviors to meet the challenges they confront. These behaviors are cued by the fishes' physiology and by environmental conditions, which together drive the timing and movement of the individuals through their life cycle. Because all species spend time in the delta, they share some environmental conditions and challenges, but their different life histories cause them also to face unique challenges. Many of the challenges are the result of anthropogenic modifications to the delta and river habitats, and these challenges are of particular concern (see Chapter 5). Some, but not all, of them are addressed in the RPAs. The information on the fishes' life histories presented below illustrates the complexity of their interactions with their environments and the potential importance of apparently small changes in the timing, direction, and magnitude of variations in flow, salinity, turbidity, water temperature, and other environmental conditions.

FISHES OF THE SALMON FAMILY

The delta provides habitat for two species of Pacific salmon, Chinook salmon (hereafter "salmon") and the rainbow trout-steelhead complex. Pacific salmon typically are anadromous. There are many exceptions, however, such as rainbow trout, which although apparently genetically identical to steelhead, are not anadromous; and there is a great deal of variation in their life histories (Williams, 2006).

When adult salmon, steelhead, and sturgeon return from the ocean and begin their upriver migration, they experience several challenges, including physical and water-quality blockages. Here the delta water system has had a great impact on populations, for 80 percent of the historical spawning habitat for Chinook salmon (Clark, 1929) and much of it for the other species has been blocked by the storage reservoirs of the Central Valley (Lindley et al., 2006). Summer temperatures in the Central Valley waterways can reach potentially lethal levels for salmon, increasing their susceptibility to disease and decreasing metabolic efficiency (Myrick and Cech, 2001, 2004). The timing of adult salmon runs leads them to avoid most of the detrimental effects of high summer temperatures because they enter the delta and swim upriver to their spawning habitats and hatcheries in the spring, autumn, and winter. Wild spawning fish excavate redds in stream reaches with loose gravel in shallow riffles or along the margins of deeper runs (NMFS, 2009), where temperatures are cooler and eggs buried in the gravel receive a sufficient flux of oxygenated water through interstitial flow. The eggs incubate for several months and after emerging the young fry either immediately begin their migration back to the ocean or spend several weeks to a year in freshwater before migrating. Because of this diversity, juvenile salmon and steelhead pass through the delta throughout the year; however, the timing and size of the migrants generally corresponds to specific runs (Lindley et al., 2006; Williams, 2006).

Salmon and steelhead undergo a complex set of physiological changes in preparation for their migration to the ocean known as "smoltification," after which the young fish are known as "smolts." The alteration of the fish's physiology to successfully osmoregulate in saltwater after beginning life in freshwater is a significant challenge that can be exacerbated by human-caused environmental changes (e.g., NRC, 2004b). Most Central Valley Chinook salmon migrate to the ocean within a few months of hatching and the smolts are less than 10 cm long, although some remain in freshwater for up to a year. Juvenile steelhead migrate to sea after one to three years in freshwater, and can be as large as 25 cm in length. Young migrating Chinook are much more vulnerable to entrainment in adverse flows than the stronger-swimming steelhead smolts.

Juvenile salmon migrants experience predation during their downstream migration through the Sacramento River or through the interior delta on their way to the sea. Fish that enter the central delta, driven by the strong tidal and pumping-induced flows, are moved through a labyrinth of channels, which further delays their migration and exposes them to additional predators (Perry et al., 2010). Finally, fish that enter the Old and Middle Rivers (OMR) can be drawn towards the SWP and CVP pumps (Kimmerer, 2008a). Juvenile salmon that successfully pass through the delta enter the ocean and spend one or more years there before returning to freshwater to spawn. Ocean survival is particularly dependent on the conditions the fish experience during the first few months they enter the saltwater (Lindley et al., 2009). Fish that are drawn into the central and southern delta by reverse flows are more vulnerable to predation than those that take a more direct path to the ocean, and other aspects of changed environmental conditions also expose them to predators (for more detail, see Chapter 5).

GREEN STURGEON

The Central Valley green sturgeon (*Acipenser medirostris*) is an anadromous fish that can reach 270 cm (nearly nine feet) in length with a maximum age of 60 to 70 years (Moyle et al., 2002). The historical distribution of green sturgeon is poorly documented, but they may have been distributed above the locations of present-day dams on the Sacramento and Feather Rivers (Beamesderfer et al., 2007). Information on the distribution of green sturgeon in the San Joaquin River is lacking. Mature green sturgeon enter the Sacramento River from the ocean in March and April. The Red Bluff Diversion Dam can impede their migrations (Heublein et al., 2009). After spawning, green sturgeon may immediately leave the river or hold over in deep pools until the onset of winter rains (Erikson et al., 2002; Heublein et al., 2009). Individuals then migrate back to the ocean and return to freshwater to spawn every two to four years (Erickson and Webb, 2007; Lindley et al., 2008)

Based on adult spawning behavior and the habitats required for green sturgeon embryo development, reproductive females likely select spawning areas with turbulent, high velocities near low-velocity resting areas. Green sturgeon spawning areas are presumed to be characterized by coarser substrates upstream of lower gradient reaches, which usually have slower velocities. Eggs and milt are released in turbulent water above deep, complex habitats; fertilized eggs drift into deeper areas and stick onto the substrate. Eggs require cool temperatures for development and hatch after approximately a week. Larval and juvenile green sturgeons are bottom-oriented and nocturnally active until a few months of age (Kynard et al., 2005). Juvenile green sturgeon migrate into seawater portions of natal estuaries as early as one and a half years old (Allen and Cech, 2007), and eventually emigrate to nearshore coastal waters by three years old. Subadults are migratory, spending their next 12 to16 years foraging in the coastal ocean and entering western estuaries during the summer (Moser and Lindley, 2007). In the ocean, green sturgeon inhabit the coastal shelf out to 100m depth with occasional, rapid vertical ascents near or to the surface (Erickson and Hightower, 2006).

DELTA SMELT

The delta smelt is a near-annual species; most individuals complete their life cycle in one year, but some survive for two years and reproduce again. Delta smelt reside in brackish waters around the western delta and Suisun Bay region of the estuary, being commonly found in salinities of 2 to 7, but the range they occupy extends from 0 (freshwater) to 15 or more (Moyle, 2002). In the winter (December to April), pre-spawning delta smelt migrate to tidal freshwater habitats for spawning, and larvae rear in these areas before emigrating down to the brackish water (Bennett, 2005). Delta smelt inhabit open waters away from the bottom and shore-associated structural features. Although delta smelt spawning has never been observed in the wild, information about related members of the smelt family suggests that delta smelt use bottom substrate and nearshore features during spawning. Juvenile and adult stages, 20-70 mm in length, are generally caught in the western delta and Suisun Bay in the landward margin of the brackish salinity zone, which may extend upstream of the confluence zone of the Sacramento and San Joaquin Rivers. Historically pre- and post-spawned fish were observed throughout the delta. In wet years, spawning adults often were observed in the channels and sloughs in Suisun Marsh and the lower Napa River.

In the brackish habitat of the western delta the flow is tidal with a net seaward movement, and so to maintain position, the juvenile fish appear to coordinate swimming behavior with the tides, occurring near the surface on the flood tides and at depth on the ebbs. However, in other regions, adaptive tidal behavior has not been observed and fish simply move with the tides, which may promote horizontal exchange to adjacent shallow water habitats. The FWS biological opinion emphasizes the complexity of this behavior (p. 651) and thus the above description is a general one that does not capture details that might be important.

The brackish zone also has higher densities of other fishes and zooplankton, suggesting that it may serve as a nursery habitat for delta smelt and other fishes (Bennett, 2005). The spawning movement of adults from their brackish habitat in the western delta landward to the freshwater portions of the delta is triggered by high flows and turbidity pulses.

This diversity of paths from the low-salinity (brackish) zone to the freshwater spawning habitats suggests that delta smelt do not have fidelity to specific structural habitats as do salmon. Instead, their upstream movement is directed by a combination of physiological and environmental cues that involve salinity, turbidity, and both net and tidal flows through the channels of the delta and its tributaries. Additionally, since 2005, approximately 42 percent of the current delta smelt population is in the Cache Slough complex north of the delta, and may represent an alternative life-history strategy in which the fish remain upstream through maturity (Sommer et al., 2009).

Historically, the complete delta-smelt life cycle occurred unobstructed throughout the delta. Human-caused changes in delta water quality and hydrodynamics have disrupted the cycle and since 2005, delta-smelt population densities have been extremely low in the traditional habitats in the central and south delta (*http://www.dfg.ca.gov/delta/data/*), and pump salvage[1] also has been extremely low, about four percent of the 50-year average index (*http://www.dfg.ca.gov/delta/data/townet/indices.asp?species=3*). Analyses seeking causes for the declines to the present condition have focused on relationships between abundance, salvage, water exports, delta flows, turbidity, and food. Kimmerer (2008b) found that delta-smelt survival between summer (juvenile) and fall (adult) was related to zooplankton biomass, suggesting that high zooplankton abundances contributed to delta-smelt abundance and residence time in the southern delta, and thus increased entrainment risk at the pumps. Grimaldo et al. (2009) found that between 1995 and 2005 the inter-annual variation in adult delta-smelt salvage was best correlated with turbidity and the interaction of OMR[2] flows and X2[3]. The annual salvage of age-0 delta smelt (fish hatched in that year, around 27 mm in length) was best correlated with spring abundance of zooplankton, OMR flows, and turbidity. Additionally, Grimaldo et al. suggested that differences in temporal patterns of entrainment of delta smelt between years may be a measure of the degree to which their physical habitat overlapped with the hydrodynamic footprint of negative OMR flows towards the pumps. However, the year-class strength of adult delta smelt was not related to salvage, al-

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[1] "Salvage" refers to fish caught in the pumps and retrieved alive to be released elsewhere in the system. It often is used as a surrogate estimate for "take" by the pumps.

[2] The term "OMR flows" refers to flows in the Old and Middle Rivers (see Figure 1-1), which are affected by the pumping of water for export. At high negative flows, that is, flows away from the sea towards the pumps in the south, the normal seaward flow associated with ebb tides can be completely eliminated.

[3] "X2" refers to the salinity isohaline of salinity 2 (a contour line of equal salinity). Sometimes X2 is used as shorthand for the mean position of that isohaline, measured in kilometers upstream from the Golden Gate Bridge over the outlet of San Francisco Bay. Managing the position of X2 is a major aspect of the delta smelt Biological Opinion and RPA; it is managed by adjusting flows of fresh water from delta reservoirs, as well as by adjusting pumping rates.

though the position of X2 was correlated with salvage at an intra-annual scale when OMR flows were negative. Other analyses showed a similar correlation (e.g., FWS, 2008).

While the correlation between OMR flows and salvage is substantial (Kimmerer, 2008b), their effect on population dynamics is not clear (Bennett, 2005; Grimaldo et al., 2009). Indirect factors could have contributed to population declines through a reduction in the size and abundance of food in the brackish zone. Overall zooplankton abundance is correlated with delta smelt survival (Feyrer et al., 2007; Grimaldo et al., 2009; Kimmerer, 2008b). Zooplankton abundance has been reduced through several factors, including the introduction of the overbite clam (*Corbula amurensis*), an efficient grazer of zooplankton in the low-salinity zone, and changes in nutrients that have altered the phytoplankton population so that cyanobacteria, which can reduce the food supply for zooplankton, have increased while diatoms have declined (FWS, 2008). The change in zooplankton species, associated with the success of invasive species in changed environmental conditions, also is probably important. It has been suggested that the position of X2 affects the size of delta smelt habitat and thus it affects the susceptibility of juvenile and adult delta smelt to pump entrainment (Feyrer et al., 2007, Kimmerer, 2008a). Furthermore, the mean position of X2 has moved inland about 10 km over the past 15 years (FWS, 2008, p. 180). However, there is no direct evidence relating these indirect effects to population numbers of smelt (Bennett, 2005; Kimmerer, 2002). In addition, delta smelt are now largely absent from the central and southern delta, while a significant portion of the remaining population exists in the Cache Slough complex to the north. These changes increase the uncertainty surrounding current estimates of delta smelt population changes in response to alterations in delta hydraulics.

4

Use of Models

MODELING SCENARIOS

Modeling of baselines and future project actions is a standard practice of evaluating impacts. Both biological opinions relied on the use of modeling scenarios (known as Studies) provided by the Operations Criteria and Plan (OCAP) biological assessment (BA) (*http://www.usbr.gov/mp/cvo/ocap_page.html*), although the extent to which such results were used in each biological opinion and in the formulation of RPAs varied significantly. The "proposed action" with reference to ESA is the continued operation of the CVP and SWP with additional operational and structural changes (USBR, 2008, Table 2-1) to the system. The U.S. Bureau of Reclamation (USBR) and the California Department of Water Resources (DWR) provided the results of the modeling conducted for simulating baseline conditions, future system components, operational strategies, and the water supply demands. In addition to simulating the water-supply deliveries of the project, the modeling also attempted to mimic the project operations associated with the regulatory environments described in operating criteria described in D-1485, D-1641,CVPIA Section 3406 (b)(2) and the Environmental Water Account (EWA) (USBR, 2008). A major difference in the current and future scenarios is the extent to which EWA is used. The purpose of EWA was to enable diversion of water by the SWP and CVP from the delta to be reduced at times to benefit fish species while minimizing uncompensated loss of water to SWP and CVP contractors (USBR, 2008, Chapter 2). The EWA is intended to replace the water loss due to pumping curtailments by purchasing surface water and groundwater from willing sellers and through increasing the flexibility of operations. The simulations include both a "full EWA" characterizing the full use of EWA assets as well as a "limited EWA" focusing only on a limited number of assets. The EWA is currently under review to determine its future (FWS, 2008, p. 34) and the RPA actions were not based on it.

Another factor that changed from current to future conditions is the way water demand by CVP/SWP users is simulated. Demands have been pre-processed using either contractual amounts and/or level of development (existing versus future). Some demands were assumed to be fixed at contractual amounts whereas in other cases they varied according to the hydrologic conditions. This topic will be considered in the committee's second report.

While several study scenarios were developed for the OCAP biological assessment (USBR, 2008), the use of modeling results in the biological opinions was largely limited to a smaller set of scenarios (Table 4-1).

Study 7.0 describes the existing condition (circa 2005), whereas Study 7.1 presents the existing condition demands with near future facilities as well as the projected modification to EWA. Study 8 describes the future condition corresponding to the year 2030 (USBR, 2008, pp. 9-33, 9-53, 9-54). Study series 9 constitutes a future condition representing modified hydrology (warm and warmer, dry and wet) along with a projected sea level rise of one foot.

CENTRAL ISSUES CONCERNING MODEL USE IN THE BIOLOGICAL OPINIONS

The USFWS and NMFS supplemented the modeling results provided by USBR and DWR with their own modeling efforts and available science on the implications of management actions on species. The primary suite of models provided to FWS and NMFS include (USBR, 2008, Chapter 9):

(a) Operations and hydrodynamic models: CalSim-II, CalLite, the Delta Simulation Model II (DSM2), including particle-tracking models (PTMs, which also are considered as surrogates for biological models)

TABLE 4-1 Key scenarios used for biological opinions of FWS and NMFS

Study	Level of Development (Year)	Environmental Water Account (EWA)	Future Project Facilities[1]	Climate and Sea Level Rise
7.0	2005	Full EWA	No	No
7.1	2005	Limited EWA	Yes	No
8.0	2030	Limited EWA	Yes	No
9.0-9.5	2030	Same as in Study 8.0[2]	Yes	Yes

[1] Future project features include South Delta Improvement Program (Stage 1), Freeport Regional Water Project, California Aqueduct and Delta-Mendota Canal intertie

[2] According to the OCAP BA (USBR, 2008), Study suite 9 is identical to Study 8.0 except for climate change and sea-level rise

(b) Temperature models: Reclamation Temperature, SRWQM, and Feather River Mode
(c) Biological models: Reclamation Mortality, and SALMOD

The modeling framework used by the agencies is diagrammed in Figure 4-1.

The USFWS, in its biological opinion, used available results from a combination of tools and data sources, including CalSim-II, DSM2-PTM, DAYFLOW historical flows, and statistical models based on observational data and particle-tracking simulations (FWS, 2008, p. 204). NMFS analyses included results from coupled CalSim-II simulations with various water-quality and biological models for a few of the life stages (NMFS, 2009, p. 64).

The CalSim-II model, the primary tool used to evaluate the water-resources implication of the proposed actions, was developed by the DWR and the USBR to simulate water storage and supply, streamflows, and delta export capability for the Central Valley Project (CVP) and the State Water Project (SWP). CalSim-II simulates water deliveries and the regulatory environment associated with the water-resources system north of the delta and south of the delta using a

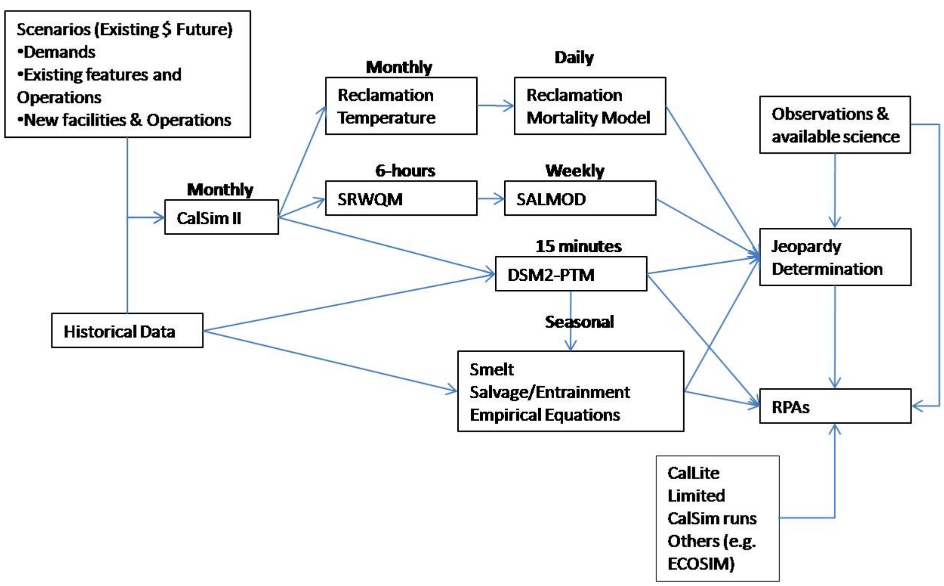

FIGURE 4-1 Modeling framework used in NMFS and USFWS biological opinions and RPAs.

single time step (one month) optimization procedure based on a linear programming algorithm. CalSim-II represents the best available planning model for the CVP-SWP system, according to a CALFED Science Program peer review by Close et al. (2003) (USBR, 2008, p. 9-4). However, many users have suggested that its primary limitation is its monthly time step, and the model should be used primarily for comparative analysis between scenarios and discouraged its use for absolute predictions (Ferreira et al., 2005; USBR, 2008, Chapter 9). In response to the peer review by Close et al. (2003), DWR and USBR provided a list of development priorities (Table 2, DWR/USBR, 2004), including the use of a daily time step, but it is not clear how many of such planned improvements have been incorporated into the version of CalSim-II used in the biological opinions.

Several other tools and models were central in effects analysis and developing RPAs, including hydrodynamic and water-quality (DSM2, USBR's temperature, SRWQM), habitat (SALMOD), and statistical and particle-tracking models (salvage, DSM2-PTM). Some of these models have already been evaluated in the literature for their individual strengths and limitations, though some (SALMOD and USBR's mortality models) have not yet been formally peer reviewed. We first review some of the challenges of applying these individual models in the determination of RPAs, and then focus on examining the modeling process, including how the models contributed to the development of RPAs, and where the uncertainties and vulnerabilities in that process lie.

Model Scale and Management Implications

Very generally, the tiered modeling approach (Figure 4-1) applied the results of CalSim-II as input to various hydrodynamic and ecological models to predict impacts of project operations and, to a very limited extent, to explore RPAs. At one level, model simulations were also used or performed to investigate the feasibility of some proposed actions. For example, CalSim-II was used at the planning level to investigate whether the USBR could meet the 1.9 MAF (at the end of September) required by actions I.2.3 and I.2.4 (maintaining cold water supplies necessary for egg incubation for the following summer's cohort of winter-run), and to recommend storage conservation in severe and extended droughts (NMFS, 2009, p. 596). Similarly, examination of CalSim results and hydrologic records demonstrated to the agencies that the first year of a drought sequence is particularly critical to storage and operations in the following drought year (NMFS, 2009, p. 596). The benefits of using models at this planning level, especially given the importance of water-year types, is clear, and there is little controversy about this application of the models.

At another level, model scenarios were examined to investigate the relationships between operations and impacts on various life stages of the fish across the water-year types and operations scenarios. For example, NMFS used DWR's Delta Survival Model (Greene, 2008) to estimate mortality of smolts associated with three CalSim-II Study scenarios (7.0, 7.1, 8.0). The USFWS used statistical models of salvage and total entrainment (Grimaldo et al., 2009; Kimmerer, 2008) to investigate the effects of proposed operations by comparing actual and predicted salvage and entrainment losses under modeled OMR flows (FWS, 2008, p. 211).

While some challenges exist in linking models in this tiered approach (see next section), concerns and controversies appear to be largely directed at the various forms of statistical relationships of salvage versus OMR flows, extrapolation of these relationships that describe impacts on single life stages to assess the population impacts on species, and the use of biological models without full consideration of their underlying uncertainties. In particular, this nested sequence of statistical models does not allow for uncertainties at one step to influence predictions at the next step. As a result, some of the RPA actions, especially those involving X2 and OMR flow triggers, are based on less reliable scientific and modeling foundations than others. In these cases, the incomplete data and resolution of the models do not closely match the resolution of the actions.

Adequacy of Current Models

Life-cycle Models

Both agencies have been criticized for the lack of adequate life-cycle models to address population level responses (e.g., Deriso, 2009; Hilborn, 2009; Manly, 2009). Nonlinear and compensatory relationships between different life-history stages are common in many fish species. Moreover, many life-history traits exhibit significant patterns of autocorrelation, such that changes in one life-history trait induce or cause related changes in others. These patterns can most effectively be understood through integrated analyses conducted in a modeling framework that represents the complete life cycle. However, complete life-cycle models were not used in either biological opinion to evaluate the effects of changes in operations. The agencies acknowledge that further model development is required, including the "cooperative development of a salmonid life-cycle model acceptable to NMFS, Reclamation (USBR), CDFG, and DWR" (NMSF biological opinion, p. 584). While one life-cycle model (Interactive Object-Oriented Salmon simulation) was available for winter-run salmon from the OCAP BA (USBR, 2008), this model was rejected based on model resolution and data limitation issues (NMFS, 2009, p. 65). Similarly, a better life-cycle model for delta smelt is critically needed (PBS&J, 2008). Such life-cycle models for delta smelt are currently under development. The committee recommends that development of such models be given a high priority within the agencies. The committee also encourages the agencies to develop several different modeling approaches to enable the results of models with different structure and assumptions to be compared. When multiple models agree, the confidence in their predictions is increased.

Particle-Tracking Models (PTMs)

Particle-tracking models (PTMs) are models that treat eggs and larval fishes as if they were particles and simulate their movements based on hydraulic models of flows. Criticisms have applied to the use of PTMs, which rely on some key assumptions (e.g., neutral buoyancy, no active swimming) that have been challenged at least for some life stages (Kimmerer and Nobriga, 2008) on the basis that fish live and move in three dimensions. Other limitations of the use of PTMs in this case include the reliance on the one-dimensional DSM2, use of random-walks to simulate lateral movements, and the lack of simulation of fish behavior. In view of these limitations, PTMs as used in this case may not be suitable for predicting the movement of fish of some life stages (juvenile and adults) where behavior becomes relevant to the question of potential entrainment (Kimmerer and Nobriga, 2008). The NMFS acknowledges these limitations, noting that "The acoustic tagging studies also indicate that fish behavior is complex, with fish exhibiting behavior that is not captured by the 'tidal surfing' model utilized as one of the options in the PTM simulations. Fish made their way downstream in a way that was more complicated than simply riding the tide, and no discernable phase of the tide had greater net downstream movement than another" (NMFS, 2009, p. 651).

However, while fish seldom behave like passive particles, results based on passive particles can provide insights. For example, the NMFS used a combination of models to simulate mortality rates of salmonids for three CalSim-II scenarios. The results were used to compare the inter- and intra-annual impacts of the three scenarios (NMFS, 2009, p. 381). Further, the agencies advocate improving the model through further study, such as Action iV.2.2, which includes an acoustic tag experiment in part to evaluate action benefits and in part to improve PTM results (USBR, 2008, p. 645). Thus, while there is uncertainty regarding the accuracy of the mortality losses, the use of the models in a comparative way is probably acceptable. However, it should be made clear how the model is used, and the explicit consideration of the PTM assumptions and uncertainties should be more clearly documented in the biological opinions.

Although there has not been an assessment of the degree to which these limitations affect the conclusions, PTM results were used for RPA development. Although the DSM2 has been calibrated adequately for OMR flows, there is no clear evidence concerning the accuracy of the PTM's ability to simulate smelt entrainment in relation to how the models are used for jeopardy determination and RPA development. This is particularly important because a number of actions driven by the RPAs recommend trigger values for OMR to curtail exports. As discussed in a later section, the science surrounding these OMR triggers is less clear than for many other aspects of the RPAs, and this trigger may result in significant water requirements. The committee's recommendations for improving the modeling and associated science are intended to improve the best science available to the agencies. The committee will address such improvements in greater detail in its second report.

Other Biological Models

The NMFS used other biological models to simulate the effects of operations on various life stages of salmon. These models involve several key assumptions and data limitations that influence the reliability of their results.

For example, SALMOD, developed by the USGS, was used by the NMFS to investigate the population level responses of the freshwater life stages to habitat changes caused by project operations (NMFS, 2009, p. 269). A variety of weekly averaged inputs are required, including streamflow, water temperature, and number and distribution of adult spawners (USBR, 2008, p. 9-25). This model provides some valuable insight, but requires greater consideration of the model assumptions (e.g., linear stream, habitat as primary limiting factor, independence of food resources on flow and temperature, density independence for some life stages) and uncertainties. Otherwise, the use of this model is limited to comparative, rather than absolute, analysis of RPA actions. Further, it would be important to investigate the sensitivity of the model to initial conditions and input data, particularly those prone to measurement error (e.g., number and distribution of spawners) to provide some indication of the reliability of model outputs. While SALMOD has not been thoroughly peer-reviewed, criticisms of similar modeling approaches (e.g., NRC, 2008) have highlighted some key issues with habitat-suitability models (e.g., the need for greater clarity concerning the assumption that habitat is a limiting factor and the need for a thorough assessment of the representativeness of the areas sampled) and have provided extensive discussions of the use of models in an adaptive-management approach, which is relevant to this committee's recommendations. Finally, the NMFS acknowledges that SALMOD is most appropriately applied to large populations that are not sensitive to individual variability and environmental stochasticity (NMFS, 2009, p. 270), which means that the predictions for the relatively small population in the delta river system are subject to considerable uncertainty. The uncertainties again highlight the need for an adaptive management approach.

The NMFS also used results from the USBR's salmon mortality model (Hydrologic Consultants, Inc., 1996) to examine daily salmon spawning losses for early life stages (pre-spawned eggs, fertilized eggs, and pre-emergent fry) due to exposure of high temperatures. Temperature-exposure mortality criteria for the three life stages are combined with modeled temperature predictions and spawning distribution data to compute percents of salmon spawning losses. Because simulations of river temperatures are run on a daily or shorter time step, downscaling of monthly CalSim-II data is required (USBR, 2008, Attachment H-1). Moreover, the monthly temperature models do not adequately capture the range of daily temperature variability (USBR, 2008, pp. 9-109). In addition, several assumptions (e.g., density independence) and important data limitations (USBR, 2008, pp. L-6, L-7) challenge the reliability of this model. Finally, while this model has been applied in other systems, it is not thoroughly peer reviewed and no analysis of sensitivity or uncertainty has been performed. Addressing these model shortcomings would help increase confidence in the analyses.

Developing, Evaluating, and Applying Best Available Models

As the agencies work within the constraints of best available science, some recognition of the adequacy and reliability of the models should be reflected in the management decisions by making them adaptive. The following five factors, in particular, need better documentation.

1. *Incompatible temporal resolution and implications for management decisions.*

The individual models used in this tiered analysis approach have a broad range of temporal resolutions (Figure 4-1). Care must be exercised in such situations so that the linkages of models with different temporal and spatial resolutions do not result in propagation of large errors that may influence decisions derived from the modeling results. For example, CalSim-II uses a monthly time step whereas the DSM2 uses a 15-minute time step. Although the tidal boundary condition in DSM2 is pre-processed at 15-minutes, average monthly flow, simulated by CalSim-II, is provided as the upstream flow boundary condition at many delta inflow points. The linkage of CalSim-II and DSM2 attempts to smooth out the step change in monthly simulated flows (USBR, 2008, pp. 9-14, 9-15), but this is not necessarily adequate to simulate the fluctuations of flows within the month. The use of the monthly time step certainly could have a significant influence on such performance measures as OMR flows, particularly when such flows are recommended in RPAs for triggering export curtailments. USFWS and NMFS should provide a comparison of daily versus monthly average simulations of DSM2 for a historical period to ascertain the reliability of using monthly CalSim output as input to DSM2.

The incompatibility of temporal resolutions is particularly important given that flows in the delta are strongly influenced by tides. The flows at such locations as Old River and Middle River are characterized by two flood-ebb cycles per day, with positive and negative values of much larger magnitude than the average net flow at these locations (Gartrell, 2010). In view of the fact that OMR flows have sub-hourly hydrodynamic components, averaging over a longer period such as 5 to 14 days to define the thresholds in the implementation of the RPAs could produce unnecessary changes in water exports. The use of monthly average flows produced by CalSim-II could further add to the concerns regarding the recommended thresholds of OMR flows. In view of these modeling uncertainties, further clarification as to how the modeled OMR flows were used for jeopardy determination and hence for the development and implementation of RPAs is needed.

2. *Inconsistent use of baselines.*

Both biological opinions use historical data along with modeling results of the CALSIM-II scenarios. Study 7.0, which represents the existing condition, is expected to be closest to historical conditions. However, important differences between the two (historical and existing conditions) could exist due to differences in demands and more importantly due to deviations in operations. Because of the simplifying assumptions used in CalSim-II historical simulations, the FWS BO opted to use actual historical data to develop their baseline (FWS, 2008, p. 206) and continued to compare historical data with the modeling results of the numerous scenarios described above (see, for example, Figures E-3 through E-19).

The results suggest that often, actual data are very different in magnitude in comparison to Study 7.0 and furthermore, most scenarios (Studies 7, 7.1, 8, and study series 9) are clumped together with relatively small differences between them in relation to the magnitude of differences with the historical data. In view of these differences, the validation of Study 7.0 and consequently others, becomes even more important for the purpose of RPA development.

The use of historical data to make inferences is very typical and appropriate in the biological opinions. However, since the evaluation of project actions and the development of RPAs are based on the evaluation of modeling scenarios, which appear to greatly differ from historical data, a comparison of the two sets of data (historical and simulated) may incur errors in interpretation. The committee recommends that the biological opinions provide a better justification for the reasonableness of the baseline scenario, Study 7.0, as well as the comparison of scenario results with historical data.

3. Challenges in calibrating and validating any of the models to historical observations and operations.

It is a standard practice to ensure the appropriate use of models through the processes of calibration and testing (ASTM, 2004; NRC 2008). Validation of CalSim-II is described in Appendix U of the OCAP BA (USBR, 2008), which provides a comparison of Study 7.0 (existing condition) with the recent historical data. A review of those results shows that there are significant deviations of the historical data from the simulated storages and exports that may be of the same magnitude as the differences between the scenarios being evaluated. Thus, while the tool itself performs well, some questions remain regarding the gross nature of generalized rules used in CalSim-II to operate CVP and SWP systems, relative to actual variability of dynamic operations (USBR, 2008, pages 9-4). In their peer review of the CalSim-II model, Close et al. (2003) suggested that "Given present and anticipated uses of CalSim-II, the model should be calibrated, tested, and documented for "absolute" or non-comparative uses." It is not clear if the agencies that developed the model have responded to this suggestion in a comprehensive manner. As emphasized above, a clear presentation of the realism of Study 7.0 with respect to recent operations or observations would help avoid the criticism as to the results of Study 7.0 as well as other derivatives of it (Studies 7.1, 8.0 and series 9).

The OCAP BA (USBR, 2008) provides sufficient information on the calibration and testing of temperature models, and the time steps vary among models, although all used the monthly output of CalSim-II in predictions. Thus, they appear to be adequate for predicting temperature variation and making comparisons at the monthly time scale. Information on the calibration of DSM2 and PTM is provided in part by DWR, which has been posted online (*http://modeling.water.ca.gov/delta/studies/validation2000/*) results of the calibration of this 1-D, hydrodynamic model of the delta. Based on the information provided, it appears to adequately mimic the historical data at a daily time-scale. However, the DSM2 simulations should demonstrate that the range of negative OMR flows used for calibration covers the high negative flows simulated by CalSim-II for future scenarios. There has been an attempt to test PTM (Wilbur, 2001), but clearly this tool needs further improvements. Wilbur (2001) reports that the existing velocity profiles used in PTM consistently over-predict the field observations (i.e., the predicted velocities exceed the observed velocities).

In addition, with the potential for changes in the historical patterns of climate and hydrology, calibrating models with historical data alone may be less meaningful for projection of future operations. Thus, in addition to providing support for model improvement and adaptive management, a more robust monitoring program will also support calibration and testing of models with more relevant representation of the current and future system. For example, drought-induced low flows of the past several years provide opportunities to calibrate and test models under infrequent but foreseeable conditions. Realistic modeling of the system that incorporates what actually happens in an operational setting with climate outlook will be important in the future.

The biological models such as USBR's mortality model and SALMOD are essentially uncalibrated for the system, and further concerns about these models were addressed in previous sections.

4. Challenges of the Tiered Modeling Approach.

Temperature, OMR flows, and X2 performance measures are particularly challenged by the tiered modeling approach, with limitations related to data availability and inconsistency in model resolution (spatial and temporal) and complexity (USBR, 2008, pp. 9-31). However, the use of models may still be beneficial in planning and triggering adaptive management needs. For example, for NMFS implementation of Action II.2 (Lower American River Temperature Management), forecasts will be used to simulate operations and compliance with thermal criteria for specific life stages in months when salmon would be present

(NMFS, 2009, p. 614). However, if the USBR determines that it cannot meet the temperature requirement, and can demonstrate this through modeling of allocations and delivery schedules, consultation with the NMFS will occur. In this example, modeling results are used to evaluate the feasibility of meeting criteria, rather than trying to derive direct loss estimates. The RPA then leads to a process for adaptive management of the temperature operations based on updates to the hydrologic information. Thus, despite the particularly challenging example of managing temperature, the use of models appears to have allowed for flexibility.

However, no qualitative or quantitative analysis of the magnitude of errors across these model linkages and the resulting uncertainties are presented. While not required for the justification of RPAs, failing to consider error propagation across the models makes it difficult to evaluate the reliability of meeting the RPAs and their ability to provide the intended benefits.

5. Lack of an integrative analysis of RPAs

Numerous RPA actions proposed in both biological opinions cover new projects as well as operational changes. However, the information provided to the committee did not include a comprehensive analysis of all RPA actions, either individually or, more important, jointly, with respect to their ability to reduce the risks to the fish or to estimate system-wide water requirements. Clearly, the agencies lacked properly linked operations/hydrodynamic/biological models at the appropriate scales for RPA development. The agencies should be complimented for using historical data as well as best available science when modeling was not adequate. However, the proposed RPAs could incur significant water supply costs, and there should be an attempt to provide an integrative analysis of the RPAs with quantitative tools. The committee also acknowledges the challenges associated with estimating water requirements for some RPAs, particularly those based on adaptive management strategies, but explicit and transparent consideration of water requirements and biological benefits of specific actions and of subsets of actions would provide the basis for a smoother implementation of the RPAs.

The committee recommends that the agencies consider investigating the use of CalSim-II and other quantitative tools (e.g., PTM, life-cycle models) to simulate appropriate RPA actions of both biological opinions. These linked models would allow an integrated evaluation of the biological benefits and water requirements of individual actions and suites of actions, and the identification of potential species conflicts among the RPAs. Although not required by the ESA, such an integrative analysis would be helpful to all concerned to evaluate the degree to which the RPAs are likely to produce biological benefits and to quantify the water requirements to those who might be affected by the future actions of the two biological opinions. In addition to further model development, efforts to improve documentation of model use would be beneficial. Documentation should include a record of the decisions, assumptions, and limitations of the models (e.g., NRC, 2008).

Thus, we find that, while used appropriately in this analysis, the PTM and biological models for both salmon and smelt should be further developed, evaluated, and documented**.** The models show promise for being quantitative tools that would allow for examination of alternative ideas about key relationships underlying the RPAs. In addition, complete life-cycle models capable of being linked to these other models should be developed. Although developing, testing, and evaluating such models would require a significant investment, the committee judges that the investment would be worthwhile in the long term.

CONCLUSION

Modeling is useful for understanding the system as well as predicting future performance. As long as modelers understand and accurately convey the uncertainties of models, they can provide valuable information for making decisions. The committee reviewed the models the agencies used to determine to what degree they used the models in developing the RPAs. The biological opinions have used results of a variety of operations, hydrodynamic, and biological models currently available to them for RPA development. However, the agencies have not developed a comprehensive modeling strategy that includes the development of new models (e.g., life-cycle and movement models that link behavior and hydrology); such models may have provided important additional information for the development of RPAs. Nonetheless, the agencies should be complimented for combining the available modeling results with historical observations and peer-reviewed literature. The committee also compliments the agencies for the extensive discussion and presentation of the rationale for the particular types of actions proposed in the RPAs.

The committee concluded that as far as they went, despite flaws, the individual models were scientifically justified, but that they needed improvements and that they did not go far enough toward an integrated analysis of the RPAs. The committee has raised several important issues related to the modeling process used, including the model scale and management information; the adequacy of models, particularly the particle-tracking model and the lack of life-cycle models; incompatibilities in both temporal and spatial scales among the models and between model output and the scale of the RPA actions; the use of baselines; inadequate calibration and testing of modeling tools (in some cases); and inadequate model documentation. A more-thorough, integrative evaluation of RPA actions with respect to their likelihood of reducing adverse effects on the listed fishes and their likely economic consequences, coupled with clear documentation would improve the credibility and perhaps the acceptance of the RPAs. Thus the committee concluded that improving the models by making them more realistic and by better matching the scale of their outputs to the scale of the actions, and by extending the modeling to be more comprehensive and to include features such as fish life cycles would improve the agencies' abilities to assess risks to the fishes, to fine-tune various actions, and to predict the effects of the actions. Three-dimensional models are more expensive and time-consuming than simpler models, but they can contribute valuable understanding if used appropriately (e.g., Gross et al., 1999; Gross et al., 2009).

In addition, the committee concludes that opportunities exist for developing a framework to improve the credibility, accountability, and utility of models used in implementing the RPAs. The framework will be particularly important for some of the more-complex actions, such as those involving Shasta and San Joaquin storage and flows, which rely heavily on model predictions. The committee plans to address such issues, including the framework mentioned above, in more detail in its second report.

5

Other Stressors

INTRODUCTION

Declines in the listed species must be considered in the context of the many changes that are occurring in the "baseline" factors in the region. While the CVP and SWP pumps kill fish, no scientific study has demonstrated that pumping in the south delta is the most important or the only factor accounting for the delta-smelt population decline. Therefore, the multiple other stressors that are affecting fish in the delta environment as well as in the other environments they occupy during their lives must be considered, as well as their comparative importance with respect to the effects of export pumping. These factors and their impacts, only some of which originate within the delta itself, will be described in greater detail in the committee's second report. Some are described here to highlight their potential importance and to underscore that a holistic approach to managing the ecology of imperiled fishes in the delta will be required if species declines are to be reversed. The factors described here are not meant to be exhaustive, but are intended to demonstrate that the effects of these factors are numerous and, in some cases, not only potentially very important but also under-characterized. Moreover, while individual relationships with these stress factors are generally weakly understood, the cumulative or interactive effects of these factors with each other and with water exports are virtually unknown and unexplored (Sommer et al., 2007).

CONTAMINANTS

It has long been recognized that contaminants are present in the delta, have had impacts on the fishes, and may be increasing (Davis et al., 2003; Edmunds et al., 1999; Linville et al., 2002). Contamination of runoff from agricultural use of pesticides has been documented and has been shown to affect invertebrates and other prey, as well as on some life stages of fish (e.g., Giddings, 2000; Kuivila and Foe, 1995; Weston et al., 2004). Kuivila and Moon (2004) found that larval and juvenile delta smelt coincide with elevated levels of pesticides in the spring. Pyrethroid insecticide use has increased in recent years. Such insecticides have been found in higher concentrations in runoff, and may be toxic to macroinvertebrates in the sediment (Weston et al., 2004, 2005); it is toxic to the amphipod *Hyalella azteca*, which is found in the delta (Weston and Lydy, 2010). The use of pyrethroids increased substantially in the recent years during which the decline of pelagic organisms in the delta became a serious concern as compared to earlier decades (Oros and Werner, 2005). Among other identified contaminants that may also have effects are selenium and mercury. Histopathological studies have shown a range of effects, from little to no effect (Foott et al., 2006) to significant evidence of impairment depending on species, timing, and contaminant biomarker.

ALTERED NUTRIENT LOADS

Nutrients have received recent attention as a potential stress factor for phytoplankton, zooplankton, and fish populations for several reasons. First, research by Wilkerson et al. (2006) and Dugdale et al. (2007) found that phytoplankton (diatom) growth in mesocosm experiments did not occur under *in situ* ammonium levels, and only increased when ammonium levels were reduced. They interpreted this finding to mean that diatom growth was suppressed under ambient ammonium levels, and only after ammonium concentrations began to be drawn down did diatoms begin to use nitrate, an alternate nitrogen form, and then proliferate.

With respect to nutrient loading effects, declines in phosphate loading may be related to declines in chlorophyll-*a* throughout the Sacramento-San Joaquin delta (Van Niewenhuyse, 2007). While these results show that chlorophyll-*a* in the water column declined coincident with the decline in phosphate in 1996, phosphate levels, both inorganic and organic, are not at extremely low concentrations in the water. Nevertheless, the effects of the rapid and substantial change in the ratio of inorganic nitrogen to inorganic phosphate in the system have yet to be adequately explored.

CHANGES IN FOOD AVAILABILITY AND QUALITY

Significant changes in the food web may have affected food abundance and food quality available to delta smelt. From changes in zooplankton to declines in chlorophyll to increases in submerged aquatic vegetation, these changes have enormous effects on the amount and quality of food potentially available for various fish species (e.g., Bouley and Kimmerer, 2006; Muller-Solger et al., 2006). The benthic community was significantly changed after the overbite clam, *Corbula amurense*, became dominant in the late 1980s; such changes have effects on food availability that may cascade through the food web to affect the abundance of delta smelt.

In addition to changes in food availability, other changes in the food web have had potentially large impacts on smelt. Since 1999, blooms of the cyanobacterium *Microcystis* have increased and are especially common in the central delta when water temperatures exceed 20°C (Lehman et al., 2005). Although delta smelt may not be in the central delta during the period of maximum *Microcystis* abundance, during dry years the spread of *Microcystis* extends well into the western delta so that the zone of influence may be greater than previously thought (Lehman et al., 2008). Most recently it has been demonstrated that the *Microcystis* toxin, microcystin, not only is present in water and in zooplankton, but histopathological studies have shown liver tissue impacts on striped bass and silversides (Lehman et al., 2010).

INTRODUCED FISHES

The delta is a substantially altered ecosystem, and that applies to the fish species present as well. Some environmental changes likely enhance the spread of nonnative species (for example warm, irregularly flowing water around dams or diversions can favor warm-water species) (FWS, 2008, p. 147), as can the presence of riprap to support banks (Michny and Hampton, 1984). Thus, the spread of nonnative species may be, at least in part, an effect of other ecosystem changes. Once nonnative species become established, they further alter the ecosystem. Some species, such as American shad (*Alosa sapidissima*) and striped bass (*Morone saxatilis*), native to the Atlantic and Gulf coasts of North America, have been present in the delta region since the late 19th century (Lampman, 1946; Moyle, 2002). Striped bass (along with the native Sacramento pikeminnow, *Ptychocheilus grandis*) have been implicated as predators on juvenile Chinook salmon, especially when they congregate below the Red Bluff Diversion Dam (Tucker et al., 2003) and other structures; at the Suisun Marsh Salinity Control Gates they were the dominant predator on juvenile Chinook salmon (Edwards et al., 1996; Tillman et al., 1996). Other introductions are more recent, and some might be more threatening to native species. For example, the silverside, *Menidia beryllina*, is becoming more widespread in the delta and likely preys on juvenile delta smelt (Moyle, 2002) or competes for similar copepod prey (Bennett and Moyle, 1996). Largemouth bass (*Micropterus salmoides*) and many other members of its family (Centrarchidae), along with various species of catfish (family Siluridae), native to the Mississippi and Atlantic drainages, also are increasing, while the lone member of the centrarchid family that was native to the region, the Sacramento perch (*Archoplites interruptus*), no longer occurs in the delta (Moyle, 2002). All the above species include fish in their diets to a greater or lesser degree, including various life stages of delta smelt at times. In addition, other species, such as common carp (*Cyprinus carpio*) and threadfin shad (*Dorosoma petenense*), are not significant piscivores, but likely compete with delta smelt for food or otherwise affect their environment. Finally, the wakasagi (*Hypomesus nipponensis*), an introduced Japanese smelt very similar to the delta smelt, is becoming increasingly widespread in the delta. It interbreeds and competes with the delta smelt and might prey on it, and its presence in the delta complicates the assessment of delta smelt populations and salvage because it is so similar to the delta smelt that it is not easy to distinguish between the two species (Moyle, 2002). Delta smelt have co-existed with many of these alien fishes for more than 100 years before the recent declines, and so the decline of smelt cannot be attributed entirely to their presence, but some species have increased recently and their effects on smelt and salmonids—including on the potential for smelt populations to recover—have not been well studied.

IMPEDIMENTS TO PASSAGE, CHANGES IN OCEAN CONDITIONS, FISHING, AND HATCHERIES

Clark (1929) estimated that 80 percent of the original spawning habitat available to Chinook salmon in California's Central Valley had been made unavailable by blockages, mainly dams, by 1928. A similar loss of habitat has occurred for Central Valley steelhead as well (Lindley et al., 2006). Dams, diversion points, gates, and screens also affect green sturgeon. Ocean conditions vary, and in general they fluctuate between periods of relatively high productivity for salmon and lower productivity (Hare et al., 1999; Mantua and Hare, 2002). Lindley et al. (2009) concluded that ocean conditions have recently been poor for salmon, although there has been a long-term, steady deterioration in freshwater and estuarine environments as well. Sport and commercial fishing for salmon, sturgeon, and steelhead has been tightly regulated both at sea and in freshwater, and in 2008, there was a complete closure of the commercial and recreational fishery for Chinook salmon (NMFS, 2009, p. 145). However, Chinook salmon make very long oceanic migrations and their bycatch in other fisheries cannot be totally eliminated (NRC, 2005). Hatchery operations have been controversial, but it is almost impossible to operate hatcheries without adverse genetic and even ecological effects on salmon (NRC, 2004b; NMFS, 2009, p. 143) or steelhead (NMFS, 2009, p. 143).

DISEASES

Histopathological studies have revealed a range of diseases of potential concern in the delta. For example, parasites have been found in threadfin shad gills, but not at a high enough infection rate to be of alarm, but evidence from endrocrine disruption analyses shows some degree of intersex delta smelt males, having immature oocytes in the testes (Anderson et al., 2003). Other investigators have found myxosporean infections in yellowfin goby in Suisun Marsh (Baxa et al., In Progress). These and other measures suggest that parasitic infections, viral infections, or other infections are affecting fish, and that interactions with other stressors, such as contaminants, may be having increasing effects on fish.

CLIMATE CHANGE

Climate change could have severe negative consequences for the listed fishes. There are at least three reasons why this is of concern. First, the recent meteorological trend has runoff from the Sierra Nevada shifting from spring to winter as more precipitation falls as rain rather than snow, and as snowmelt occurs earlier and faster because of warming, increasing the likelihood and frequency of winter floods and altered hydrographs, and thus changes in the salinity of delta water (Knowles and Cayan, 2002, 2004; Roos, 1987, 1991). Alteration of precipitation type and timing of runoff may affect patterns in reproduction of the smelt and migration of salmon and sturgeon (Moyle, 2002). Additionally, effects of sea-level rise will increase salinity intrusion further upstream, again impacting fish distributions that rely on salinity gradients to define habitat; their habitat will be reduced. Lastly, as climate warms, so too does the water. This will impact fish distributions in several ways. Temperature is a cue for many biological processes, so many stages of the life cycle are likely to be affected. Moreover, warmer water will mean proportionately more days in which the temperature is in the lethal range, ~25°C (Swanson et al., 2000). The effects of these climate consequences are less suitable habitat for delta smelt in future years as well as threats to the migration of anadromous species like salmon and sturgeon.

CONCLUSION

Based on the evidence summarized above, the committee agreed that the adverse effects of all the other stressors on the listed fishes are potentially large. Time did not permit full exploration of this issue in this intense first phase of the committee's study. The committee will explore this issue more thoroughly in its second report.

6

Assessment of the RPAs

INTRODUCTION

The RPAs include many specific actions that fall into several categories for each species. The RPA in the FWS biological opinion for delta smelt focuses on limiting OMR negative flows in winter to protect migrating adults (Actions 1 and 2) and to protect larval smelt (Action 3) from entrainment at the export pumps. It also aims to protect estuarine habitat for smelt during the fall by managing the position of X2 (Action 4). Action 5 is to protect larval and juvenile smelt from entrainments by refraining from installing the Head of Old River Barrier (HORB) depending on conditions; if the HORB is installed, then the Temporary Barrier Project's gates would remain open. Finally, Action 6 calls for restoration and construction of 8,000 acres of intertidal and tidal habitat.

The RPA in the NMFS biological opinion for Chinook salmon, Central Valley steelhead, and green sturgeon is divided into far too many specific actions (72) to summarize here, but the biological opinion describes 10 major effects of the RPA on the listed species. They include management of storage and releases to manage temperature in the Sacramento River for steelhead and salmon; maintaining flows and temperatures in Clear Creek for spring-run Chinook salmon; opening gates at the Red Bluff Diversion Dam (RBDD) at critical times to promote passage for salmon and sturgeon; improving rearing habitat for salmon in the lower Sacramento River and in the northern delta; closure of the gates of the Delta Cross Channel (DCC) at critical times to keep juvenile salmon and steelhead out of the interior delta and instead allowing them to migrate out to sea; limiting OMR negative flows to avoid entrainment of juvenile salmon; increased flows in the San Joaquin River and curtailment of water exports to improve survival of San Joaquin steelhead smolts, along with an acoustic tagging program to evaluate the effectiveness of this action; flow and temperature management on the American River for steelhead; a year-round flow regime on the Stanislaus River to benefit steelhead; and the development of Hatchery Genetics Management Plans at the Nimbus (American River) and Trinity River hatcheries to benefit steelhead and fall-run Chinook salmon.

Rather than review every action and every detail, the committee comments on the broader concepts at issue and general categories of actions. Three important goals are to consider how well the RPAs are based on available scientific information; whether there are any potential RPAs not adopted that would have lesser impacts to other water uses as compared to those adopted in the biological opinions, and would provide equal or greater protection for the listed fishes; and whether there are provisions in the FWS and NMFS biological opinions to resolve potential incompatibilities between them. In addition we assess the integration of the RPAs within and across species and across all actions.

Addressing these goals requires explicitly recognizing the fundamental differences in the main conflicting arguments. There is concern, on one hand, that the increasing diversions of water from the delta over a period of many decades and the alteration of the seasonal flow regime have contributed to direct effects on populations of native species through mortality at the pumps, changes in habitat quality, and changes in water quality; and to indirect, long-term effects from alterations of food webs, biological communities, and delta-wide habitat changes. The RPAs propose that their collective effects will offset the impacts of the proposed operations of the SVP and the CWP by manipulating river flows and diversions, along with other actions. An alternative argument is that the effects of water diversions on the listed fishes are marginal. It is argued that the changes imposed by the RPAs would result, therefore, only in marginal benefits to the species, especially now that the delta environment and its biota have been altered (to a new ecological baseline) by multiple stressors. Those stressors obviously include water exports, but this argument suggests a smaller role for water exports in causing the fish declines and hence a smaller role for managing the exports to reduce or halt those declines. However, even with the copious amounts of data available, it is difficult to draw conclusions about what variable or variables are most important among the pervasive, irregular, multivariate changes in the system that have occurred over the past century.

The committee's charge was to provide a scientific evaluation, not a legal one, and that is what is presented below. Nothing in this report should be interpreted as a legal judgment as to whether the agencies have met their legal requirements under the ESA. The committee's report is intended to provide a scientific evaluation of agency actions, to help refine them, and to help the general attempt to better understand the dynamics of the delta ecosystem, including the listed fishes.

DELTA SMELT

Actions Related to Limiting Flow Reversal on the Old and Middle Rivers (OMR)

The general purpose of this set of actions is to limit the size of the zone of influence around the water-diversion points at critical times. The actions would limit negative OMR flows (i.e., toward the pumps) by controlling water exports during crucial periods in winter (December through March) when delta smelt are expected to be in the central delta (FWS, 2008). The data supporting this approach show an increase in salvage of delta smelt as OMR flows become more negative. However, there are important disagreements about how to express salvage and the choice of the trigger point or threshold in negative flows above which diversions should be limited.

An important issue is whether and how salvage numbers should be normalized to account for delta smelt population size. An increase in salvage could be due to an increase in the number of smelt at risk for entrainment, an increase in negative flows that bring smelt within range of the pumps, or both. Thus, an increase in salvage could reflect a recovery of the smelt population or it could reflect increasingly adverse flows toward the pumps for the remaining smelt population. The biological opinion (FWS, 2008) recognizes this relationship, and that is why salvage is used to calculate the percentage of the population entrained, rather than absolute numbers (FWS, 2008, Figures E-4 and E-5). However, the historical distribution of smelt on which the relationship with OMR flows was established no longer exists. Delta smelt are now sparsely distributed in the central and southern delta (*www.dfg.ca.gov/delta/data*), and pump salvage also has been extremely low, less than four percent of the 50-year average index. Since 2005, a significant portion of the remaining smelt population, 42 percent (Sommer et al., 2009), is in the Cache Slough complex to the north and is therefore largely isolated from the central delta. These changes in the distribution of delta smelt increase the uncertainty surrounding current estimates of the population and its likely response to alterations in delta hydraulics, and until the numbers of smelt rise closer towards the pre-2005 levels, they do not provide a reliable index for incorporation into models for the effects of pumping on smelt salvage.

Different authors have taken different statistical approaches to analyzing the data to interpret the relationship between OMR flows and effects on smelt, and thus chose different thresholds at which OMR flows should be limited. The choice of the limit to negative flows in the RPA gives the benefit of the doubt to the species. But there are important uncertainties in the choice. The different trigger points suggested by the different analyses have important implications for water users. The committee concludes that until better monitoring data and comprehensive life-cycle and fish-movement models are available, it is scientifically reasonable to conclude that high negative OMR flows in winter probably adversely affect smelt. We note as well that actions 1 and 2 of the FWS RPA are adaptive in that they depend for their implementation on a trigger related to measured turbidity and measured salvage numbers; they also may be suspended during three-day average flows of 90,000 cfs or greater in the Sacramento River at Rio Vista and 10,000 cfs or greater in the San Joaquin River at Vernalis. However, the portion of the existing smelt population in the Cache Slough complex appears not to move downstream towards the brackish areas (Sommer et al., 2009) and thus they should be largely insulated from the effects of the OMR flows and actions 1 and 2.

The biological benefits and the water requirements of this action are likely to be sensitive to the precise values of trigger and threshold values. There clearly is a relationship between OMR flows and salvage rates, but the available data do not permit a confident identification of the threshold values to use in the action, and they do not permit a confident assessment of the benefits to the population of the action. As a result, the implementation of this action needs to be accompanied by careful monitoring, adaptive management, and additional analyses.

Some monitoring and reporting is required in RPA component 5 (monitoring and reporting). However, more should be required, recognizing limits to the agencies' and operators' human and fiscal resources. Given the uncertainties in any choice of a trigger point, a carefully designed study that directly addresses measures of the performance (effectiveness) of the action is essential. This could include monitoring of variables like salvage at the pumps and numbers of delta smelt adults and larvae at the south ends of OMR channels during pumping actions, but it should also include other variables that might affect both salvage and populations. History shows that salvage and delta smelt indices have been insufficient for such an analysis alone, partly because the populations are small and partly because of the uncertainties in the salvage numbers (e.g., to what degree do they accurately reflect mortality, and to what degree are they affected by sampling error?). This deficiency in the data needs to be remedied. But other "proximate" measures such as monitoring of flows over the tidal cycle between and during the pumping limitations could help to understand the driving mechanism for the predicted entrainment mortality associated with pumping. Measuring mean daily discharges also is not sufficient. Temperature, salinity, turbidity, and possibly other environmental factors should also be monitored at appropriate scales as this action is implemented, to determine the availability of suitable habitat in the south delta during periods of reduced pumping. Information also is needed on how fish movement is affected by the immediate water-quality and hydraulic environment they experience. Because the effectiveness of the pumping needs to be expressed in terms of the population, the influence of pumping needs to be identified in more life-stage and area specific measures, In particular, the relevance of the Cache Slough complex needs to be resolved in assessing the effectiveness of pumping restrictions. In addition, because uncertainty is high regarding several aspects of this action, it would be helpful to include an accounting of the water requirements. Ongoing evaluation of performance measures could ultimately reduce the water requirements of actions and increase the benefits to the species. Addressing the effectiveness of the proposed actions on a long-term basis could also support consensus conclusions about the effectiveness of specific actions and increase public trust. To the degree that such studies could be jointly planned and conducted by the agencies and other interested parties, transparency and public trust would be enhanced.

X2 Management for Delta Smelt

Although the mean position of X2, the isohaline (contour line of equal salinity) of total salinity 2, is a measure of the location of a single salinity characteristic, it is used in this system to indicate the position and nature of the salinity gradient between the Sacramento River and San Francisco Bay. The position of X2 is measured in kilometers from the Golden Gate Bridge. In the RPA, it has been used by the agencies as a measure of the amount of smelt habitat—influenced by salinity as well as temperature and turbidity, which are also driven by the river-estuary interaction—and thus to approximate the seasonal extent and shifting of that habitat within the ecosystem. By this reasoning, the position of X2 affects the size of delta smelt habitat (Feyrer et al., 2007; Kimmerer, 2008a).

The RPA's action 4 (FWS, 2008, page 369) proposes to maintain X2 in the fall of wet years at 74 km east of the Golden Gate Bridge and in above-normal years at 81 km east. (The action was restricted to wetter years in response to consultation with the NMFS, which expressed concern that in drier years, this action could adversely affect salmon and steelhead [memorandum from FWS and NMFS to this committee on coordination, January 15, 2010].) The action is to be achieved primarily by releases from reservoirs. The objective of the component is to manage X2 to increase the quality and quantity of habitat for delta smelt growth and rearing.

The relationship between the position of X2 and habitat area for delta smelt, as defined by smelt presence, turbidity, temperature, and salinity (Nobriga et al, 2008; Feyrer et al., in review), is critical in designing this action. A habitat-area index was derived from the probability of occurrence estimates for delta smelt (fall mid-water trawl survey, FMT) when individuals are recruiting to the adult population. Presence/absence data were used because populations are so small that quantitative estimates of populations probably are unreliable. The authors show a broad relationship between the FMT index and salinity and turbidity, supporting the choice of these variables as habitat indicators. The statistical relationship is complex. When the area of highly suitable habitat as defined by the indicators is low, either high or low FMT indices can occur. In other words, delta smelt can be successful even when habitat is restricted. More important, however, is that the lowest abundances all occurred when the habitat-area index was less than 6,000 ha. This could mean that reduced habitat area is a necessary condition for the worst population collapses, but it is not the only cause of the collapse. Thus, the relationship between the habitat and FMT indexes is not strong or simple. Above a threshold on the x-axis it allows a response on the y-axis (allows very low FMT indices).

The controversy about the action arises from the poor and sometimes confounding relationship between indirect measures of delta smelt populations (indices) and X2. The weak statistical relationship between the location of X2 and the size of smelt populations makes the justification for this action difficult to understand. In addition, although the position of X2 is correlated with the distribution of salinity and turbidity regimes (Feyrer et al., 2007), the relationship of that distribution and smelt abundance indices is unclear. The X2 action is conceptually sound in that to the degree that habitat for smelt limits their abundance, the provision of more or better habitat would be helpful. However, the examination of uncertainty in the derivation of the details of this action lacks rigor. The action is based on a series of linked statistical analyses (e.g., the relationship of presence/absence data to environmental variables, the relationship of environmental variables to habitat, the relationship of habitat to X2, the relationship of X2 to smelt abundance), with each step being uncertain. The relationships are correlative with substantial variance being left unexplained at each step. The action also may have high water requirements and may adversely affect salmon and steelhead under some conditions (memorandum from FWS and NMFS, January 15, 2010). As a result, how specific X2 targets were chosen and their likely beneficial effects need further clarification.

The X2 action for delta smelt includes a requirement for an adaptive management process that includes evaluation of other possible means of achieving the RPA's goal and it requires the establishment and peer review of performance measures and performance evaluation. It also requires "additional studies addressing elements of the habitat conceptual model" to be formulated as soon as possible and to be implemented promptly. Finally, it requires the FWS to "conduct a comprehensive review of the outcomes of the Action and the effectiveness of the adaptive management program ten years from the signing of the biological opinion, or sooner if circumstances warrant." This review is to include an independent peer review; the overall aim is to decide whether the action should be continued, modified, or terminated. It is critical that these requirements be implemented in light of the uncertainty about the biological effectiveness of the action and its high water requirements.

Tidal Habitat Action

The proposed RPA calls for the creation or restoration of 8,000 acres of intertidal and associated subtidal habitat in the delta and in Suisun Marsh. A separate planning effort also is under way for Suisun Marsh. The justification provided in the biological opinion is that the original amount of approximately 350,000 acres of tidal wetland has been reduced to less than 10,000 acres today, that the near-complete loss of tidal wetlands threatens delta smelt by reducing productivity at the base of the food web, and that delta smelt appear to benefit from the intertidal and subtidal habitat in Liberty Island, which includes tidal wetlands. This action has been less controversial than the others because it does not directly affect other water users.

However, although the concept of increasing and improving habitat to help offset other risks to smelt is conceptually sound, the scientific justification provided in the biological opinion is weak, because the relationship between tidal habitat and food availability for smelt is poorly understood, and it is inadequate to support the details of the implementation of this action. The opinion notes the importance of high-quality food sources to delta smelt and the association of these food resources with tidal habitats (including wetlands), and it references recent monitoring data from Liberty Island showing that such freshwater tidal habitats can be a source of high-quality phytoplankton that contribute to the pelagic food web downstream (p. 380). However, the specifics of which attributes of tidal habitat are essential to providing these food sources are not addressed.

In addition, the California Department of Fish and Game has raised questions about the details of this action (Wilcox, 2010). They include questions about the relative benefits of vegetated tidal marsh as opposed to open water; the extent to which invasive clams may divert new primary production; the amount of suitable productivity exported from restoration areas; the potential effect of the restored habitat on predation; the importance of productivity from vegetated tidal marsh directly or indirectly to the smelt; and the degree to which other fish species might use the habitat, possibly to the detriment of the smelt In briefings to the panel, the importance of ongoing studies in resolving these issues was identified. Identifying the characteristics of the "intertidal and associated sub-tidal habitat" that the action is expected to produce is needed to ensure that expectations of the outcomes, in terms of both habitat type and species benefits, are clear to all. The relative roles of areas of emergent vegetation, unvegetated intertidal and shallow, highly turbid subtidal habitat must be identified for the action to be effectively implemented.

The committee recommends that this action be implemented in phases, with the first phase to include the development of an implementation and adaptive management plan (similar to the approach used for the floodplain habitat action in the NMFS biological opinion), but also to explicitly consider the sustainability of the resulting habitats, especially those dependent on emergent vegetation, in the face of expected sea-level rise. In addition, there should be consideration of the types and amounts of tidal habitats necessary to produce the expected outcomes and how they can be achieved and sustained in the long term. More justification for the extent of the restoration is needed. The committee supports the monitoring program referred to in Action 6, and appropriate adaptive management triggers and actions.

SALMONIDS AND STURGEON

The NMFS RPA for salmon, steelhead, and green sturgeon is a broad complex of diverse actions spanning three habitat realms: tributary watersheds, the mainstem Sacramento and San Joaquin Rivers, and the delta. On balance, the actions are primarily crafted to improve life-stage-specific survival rates for salmon and steelhead, with the recognition that the benefits also will accrue to sturgeon. The committee agrees with this approach. The conceptual bases of the strategies underpinning many of the individual actions are generally well-founded, although the extent to which the intended responses are likely to be realized is not always clear. Given the absence of a clear, quantitative framework for analyzing the effects of individual and collective actions, it is difficult to make definitive statements regarding the merits of such a complex RPA. Indeed, absent such an analysis, the controversial aspects of some of the RPA actions could detract from the merits of the rest of the RPA.

The assortment of actions among the three habitat realms (watersheds, mainstem rivers, and delta) is designed to improve survival and to enhance connectivity throughout this system. This approach is consistent with the contemporary scientific consensus on improving ecosystem functioning as a means to improve productivity of anadromous and other migratory species (e.g., NRC 1996, 2004a, 2004b; Williams 2005). Watershed actions would be pointless if mainstem passage conditions connecting the tributaries to, and through, the delta were not made satisfactory.

Watershed and Mainstem River Actions

Watershed-level actions that are implemented in the tributaries are organized and formulated to meet the needs of specific listed populations in that system. The actions target limiting factors specific to those locales and populations. In general, the rationale for conducting the actions appears to be well-founded. However, it is difficult to ascertain to what extent, or even whether, the collective actions will appreciably reduce the risk to the fishes within the watershed or throughout the entire river system. We suggest that inclusion of some type of quantitative analysis using a tool like Ecosystem Diagnosis and Treatment (EDT) model during the planning process may have provided an even stronger justification for the set of actions selected (*http://jonesandstokes.com/*). We understand there is a recent application of EDT in the lower San Joaquin River, by Jones & Stokes, thus providing a precedent for its use in California's Central Valley. EDT is presented here as an example of a quantitative modeling approach that integrates the effects of various actions to produce relative changes in productivity and abundance. The committee emphasizes the need for a quantitative assessment framework, and does not necessarily specifically advocate the use of EDT.

The RPA also prescribes actions to improve mainstem passage conditions, most notably at the Red Bluff Diversion Dam (RBDD). The objective is to provide unobstructed upstream passage at the RBDD, to ensure more efficient access of adult salmonids to restored watersheds, and access for adult sturgeon to spawning grounds. Without such actions connectivity could not be fully realized. Furthermore, the passage improvement at the diversion dam, in combination with increased water delivery from storage reservoirs, is expected to improve smolt survival during downstream migration. This component is well justified scientifically, although the absence of a system-wide salmon survival model limits our ability to evaluate the extent to which this action contributes to improved survival for the populations in question.

Smolt Survival Near and Through the Delta

The net survival of salmonid smolts though the mainstem rivers and the delta under different water-management operations is of keen interest. Several RPA actions are intended to improve survival of the juveniles as they migrate seaward. Some of these actions have significant water requirements, and so they are controversial. The common goal of these actions is improve smolt survival by retaining a high proportion of the migrating smolt population in the mainstem Sacramento and San Joaquin Rivers. This involves two general approaches: block entrances to the interior delta, or manipulate currents in major channels to reduce the transport of smolt towards the pump facilities and possible entrainment or locations where they may be lost to predation, starvation, or disease. Here we focus on three pivotal actions: the closure of the Delta Cross Channel, the manipulation of OMR flows, and water-management actions in the lower San Joaquin River.

Delta Cross Channel (DCC)

As smolts migrate seaward from the upper Sacramento River they encounter the DCC near Walnut Grove. The DCC can at times draw large volumes of water from the Sacramento River, and some of the smolts follow that current toward the interior delta, where salmon mortality is high.

The objective of this action is to physically block the entrance of the DCC at strategic times during the smolt migration, thereby preventing access to the interior delta. This is a long-standing action that appears to be scientifically justified. However, Burau et al. (2007) estimated that when the DCC gates are open, approximately 45 percent of the Sacramento River flow measured at Freeport is redirected into the delta interior through the DCC and Georgiana Slough. The salmon action (Action Suite IV.1), which under certain triggers requires prolonged closure of the DCC gates from October 1 through June 15, must also consider the effects on delta smelt. The Smelt Working Group (notes from June 4, 2007 meeting) concluded that there could be a small beneficial effect on delta smelt from having the DCC gates open from late May until mid-June.

Although this action does not appear to constitute an important conflict between the needs of smelt and salmon, it illustrates the potential for conflict among the two opinions and the need for closer integration of the actions within the delta that have consequences for more than one of the listed species. This is an example where a systematic analysis of the implications for both species of actions would seem to be a scientific requirement.

Managing OMR Flows for Salmonids

This RPA action (IV.2.3, Old and Middle River Flow Management) also seeks to limit smolt excursion into part of the delta associated with high smolt mortality, but it does so by manipulating current direction and intensity within the Old and Middle River (OMR) drainages. The objective is to reduce current velocity toward the SWP and CVP facilities, thereby exposing fewer smolts to pump entrainment and being drawn into other unfavorable environments.

To accomplish the objective, the action calls for, reducing exports from January 1 through June 15, as necessary, to limit negative OMR flows to -2,500 to -5,000 cfs, depending on the presence of salmonids. The reverse flow will be managed within this range to reduce flows toward the pumps during periods of increased salmonid presence. The flow range was established through correlations of OMR flow and salmon entrainment indices at the pumps, and from entrainment proportions derived using the particle-tracking model (PTM). While the flow management strategy is conceptually sound, the threshold levels needed to protect fish is not definitively established. The response of loss at the pumps to OMR flow (e.g. figure 6-65 from NMFS, 2009) does not suggest a significant change in the vicinity of the flow triggers, but it does suggest that the loss rate increases exponentially above the triggers. The PTM suggests a gradual linear response in the vicinity of the trigger. However, no analysis was presented for the entrainment rate above the trigger (Figure 6-68 from NMFS, 2009), and it is not clear whether the salvage *rates* as well as salvage numbers were modeled. Therefore, the committee is unable to evaluate the validity of the exponential increase in loss rate above the trigger. Uncertainty in the effect of the flow triggers needs to be reduced, and more flexible triggers that might require less water should be evaluated.

The committee concludes that the strategy of limiting net tidal flows toward the pump facilities is sound, but the support for the specific flows targets is less certain. In the near-term telemetry-based smolt migration and survival studies (e.g, Perry and Skalski, 2008) should be used to improve our understanding of smolt responses to OMR flow levels. Reliance on salvage indices or the PTM results alone is not sufficient.

Additionally, there is little direct evidence to support the position that this action alone will benefit the San Joaquin salmon, unless it is combined with an increase in San Joaquin River flows. Furthermore, we understand this and other flow management actions are coordinated with the delta smelt actions. But we found no quantitative analysis that integrates across the actions to systematically evaluate their aggregate effects on both salmonids and smelt. Understanding those interactions will benefit from the development and use of multiple single-species models, including movement models.

Managing Exports and Flows in the San Joaquin River

The objective of this action (IV.2.1) is to reduce the vulnerability of emigrating Central Valley steelhead within the lower San Joaquin River to entrainment into the channels of the south delta and at the pumps by increasing the inflow-to-export ratio. It seeks to enhance the likelihood of salmonids' successfully exiting the delta at Chipps Island by creating more suitable hydraulic conditions in the mainstem of the San Joaquin River for emigrating fish, including greater net downstream flows.

The action has two components: reducing exports, and augmenting San Joaquin River flows at Vernalis. The rationale that increasing San Joaquin inflows to the delta will benefit smolt survival through this region of the delta is based on data from coded-wire tags on smolts. This statistical evidence provides only a coarse assessment of the action, but it indicates that increasing San Joaquin River flows can explain observed increases in escapement. Historical data indicate that high San Joaquin River flows in the spring result in higher survival of outmigrating Chinook salmon smolts and greater adult returns 2.5 years later (Kjelson et al., 1981; Kjelson and Brandes, 1989), and that when the ratio between spring flows and exports increase, Chinook salmon production increases (CDFG, 2005; SJRGA, 2007). In its biological opinion, NMFS therefore concludes that San Joaquin River Basin and Calaveras River steelhead would likewise benefit under higher spring flows in the San Joaquin River in much the same way as fall-run Chinook do. NMFS recognizes this assumption is critical, and thus the biological opinion calls for implementation of a six-year smolt-survival study (acoustic tags) (Action IV.2.2), using hatchery steelhead and fall Chinook.

The controversy lies in the effectiveness of the component of this action that reduces water exports from the delta. The effectiveness of reducing exports to improve steelhead smolt survival is less certain, in part because within the VAMP (Vernalis Adaptive Management Plan) increased flows and reduced exports are combined, and in part because steelhead smolts are larger and stronger swimmers than Chinook salmon smolts. Furthermore, it is not clear in the biological opinion how managing exports for this purpose would be integrated with export management for other actions. The choice of a 4:1 ratio of net flows to exports appears to be the result of coordinated discussions among the interested parties. Given the weak influence of exports in all survival relationships (Newman, 2008), continued negotiation offers opportunities to reduce water use in this specific action without great risk to steelhead. Further analysis of VAMP data also offers an opportunity to help clarify the issue.

The committee concludes that the rationale for increasing San Joaquin River flows has a stronger foundation than the prescribed action of concurrently managing inflows and exports. We further conclude that the implementation of the six-year steelhead smolt survival study (action IV.2.2) could provide useful insight as to the actual effectiveness of the proposed flow management actions as a long-term solution.

Increase Passage through Yolo Bypass

This action would reduce migratory delays and loss of adult and juvenile salmon and green sturgeon at structures in the Yolo Bypass. For sturgeon there is substantial evidence that improved upstream passage at Yolo will be beneficial. For salmon, the purpose is to route salmon away from the interior delta and through a habitat that is favorable for growth. This action is scientifically justified and prudent, but its implications for the routing of flows through the system as a whole were not transparently evaluated. For example, moving water through the Yolo Bypass results in less water coming through the Sacramento River. Were the effects of less flow in the Sacramento River considered in the design of the action? Similarly, how were the possible negative consequences of increased flooding of the Yolo Bypass on mercury cycling considered? This exemplifies a general tendency throughout the discussion of the actions to focus on the biologically beneficial aspects but to not fully present how any conflicting consequences or potential for such consequences were considered.

Floodplain Habitat

The floodplain habitat actions (Actions I.6.1-4) involve increasing the inundation of private and public lands within the Sacramento River basin to increase the amount and quality of rearing habitat for juvenile salmon. This action suite appears scientifically justified on the basis of a number of studies (e.g., Moyle et al., 2007; Sommer et al., 2001; Whitener and Kennedy, 1999). Given the strong basis, the committee recommends early implementation of these actions providing the implications for releases and routing of flows on other actions, and any potential negative consequences, e.g., mobilization of mercury, are adequately considered. In addition, the committee suggests detailed studies of the outcome of these actions to provide important data for improved life cycle models for these species.

INTEGRATION OF RPAs

The RPAs lack a quantitative analytical framework that ties them together within species, between smelt and salmonid species, and across the watershed. This type of systematic, formalized analysis is necessary to provide an objective determination of the net effect of the actions on the listed species and on water users.

An additional overall, systematic, coordinated analysis of the effect of all actions taken together and a process for implementing the optimized, combined set of actions would help to establish the credibility of the effort overall. Instances of coordination certainly exist. For example, the analysis done by NMFS for the Action IV.2.1 (Appendix 5), is an example of coordination, where the water needs for the 4-to-1 flow-to-export ratio for steelhead were determined and used to refine the action. But coordination is not integration. The lack of a systematic, well framed overall analysis is a serious deficiency. The interagency effort to transparently reach consensus on implications of the combined RPAs for their effects on all the species and on water quality and quantity within the delta and on water operations and deliveries should use scientific principles and methods in a collaborative and integrative manner. Full documentation of decisions is an essential part of such an effort, as is inclusion of the environmental water needs of specific actions and for the entire RPA.

It is clear that integrative tools that, for example, combine the effect over life stages into a population-level response would greatly help the development and evaluation of the combined actions. This was acknowledged by the FWS and NMFS, as well by many of the other presenters during the two days of public session of the committee meeting. There has been significant investment in operations and hydrodynamic models for the system, which have been invaluable for understanding and managing the system. An investment in ecological models that complement the operations and hydrodynamics models is sorely needed. This issue has been raised repeatedly in peer reviews, but still has not been incorporated in the NMFS and FWS analyses. Without a quantitative integration tool, the expected effects of individual actions on the listed species will remain a matter of judgment based on the interpretation of many disparate studies. The NMFS and FWS had to therefore determine the cumulative effects of the multiple actions in each RPA in a qualitative manner. This leads to arguments and disputes that are extremely difficult to resolve and that can undermine the credibility of the biological opinions. Commitment to a long-term effort to develop a quantitative tool (or tools) should be part of the RPA, with the explicit goal of formalizing and focusing the sources of disagreement and allowing for the clear testing of alternative arguments.

Transparent consideration of the implications of water requirements also would seem well advised because some of the actions have significant water requirements. DWR and NMFS used CalSim-II and Calite to simulate a collection of actions to determine water needs associated with the NMFS RPA, and concluded that they would amount to 5-7 percent of total water allocations (NMFS, 2009). (Because the actions involving negative OMR flows were similar in timing and magnitude in both the NMFS and the FWS RPAs, all OMR flow management was included in this estimate.) Those, and complementary efforts, should be extended to as many of the actions in combination as feasible, recognizing that the adaptive nature of many aspects of the RPAs, along with variations in environmental conditions and in water demands, limit the degree of certainty associated with such estimates. Credible documentation of the water needed to implement each action and the combined actions, would enable an even clearer and more logical formulation of how the suite of actions might be coordinated to simultaneously benefit the species and ensure water efficiency.

OTHER POSSIBLE RPAs

The committee's charge included the task that the committee should identify, if possible, additional potential RPAs that would provide the potential to provide equal or greater protection to the fishes than the current RPAs while costing less in terms of water availability for other uses. The committee considered RPAs that had been considered and rejected by the agencies or that were recommended to the committee for its consideration (Hamilton, 2010). They included using bubble-curtain technology instead of hard barriers to direct migration of salmon and steelhead smolts, use of weirs to protect wild steelhead from interbreeding and competition, use of weirs to reduce spring-run Chinook from inbreeding and competition with fall-run Chinook, habitat restoration and food-web enhancement, restoration of a more-natural hydrograph, reducing mortality caused by nonnative predators, reducing contaminants, reducing other sources of 'take," implementation of actions to reduce adverse effects of hatcheries, and ferrying San Joaquin River steelhead smolts through the delta.

Some of these are already included to some degree in the RPAs (e.g., reduction of adverse hatchery effects, habitat restoration), and some might not be within the agencies' authorities as RPA actions under the ESA (e.g., contaminant reduction and reduction of other sources of "take"). The committee did not attempt to evaluate whether these suggestions represent good actions to help reduce risks to the listed species in a general attempt at restoration, as that will be addressed in the committee's second report. The committee concludes that none of the above suggested alternative RPAs has received sufficient documentation or evaluation to be confident at present that any of them would have the potential to provide equal or greater protection for the listed species while requiring less disruption of delta water diversions.

Several long-term actions described above have the potential to increase protections for the species while requiring the use of less water for that purpose, because they will result in a better understanding of the system. That better understanding should allow for a better matching of water for species needs, thus potentially reducing the amount of water used in less-effective actions. However, no short-term measure was identified that would provide equal protection to the fishes while reducing restrictions on water diversions.

RESOLVING INCOMPATIBILITIES BETWEEN THE RPAs

The committee noted in its discussion of the Delta Cross Channel action for salmon that it has a small potential for conflict with the requirements for smelt, although the action itself includes a consideration of the effects on smelt. In addition, the agencies have coordinated, and in some cases changed, their actions to avoid or reduce such conflicts, including actions concerning the installation of a "non-physical" barrier at the Head of Old River and the possibility of constructing a barrier across Georgiana Slough (NMFS and FWS, 2010). However, as the committee has noted elsewhere, coordination is not integration, and while it commends the agencies for working together to avoid incompatibilities between the RPAs, it concludes that this coordination is not sufficient to achieve the best results or full evaluation of incompatibilities. To achieve those goals requires an integrated analysis, because without such an analysis it is difficult or impossible to properly evaluate potential conflicts among RPA actions. More important, such an analysis would help to produce more-effective actions. The lack of an integrated analysis also prevented the committee from a fuller evaluation of potential incompatibilities between the RPAs.

EXPECTATIONS AND PROXIMATE MEASURES

The committee heard several times at the public sessions that the RPA actions for delta smelt are not working as there has been no response in the standard annual abundance indices during the last three years when action-related restrictions have been imposed. Such comments are appropriate, but only if realistic expectations are used to judge effectiveness. In this case, it is unrealistic to expect immediate and proportional responses to actions in annual indices of delta smelt, especially within the first few years of implementation. There are several reasons for this. First, fish abundances are influenced by many factors not affected by the actions. This is true in all estuarine and marine systems, and is simply inherent in fish population dynamics. For example, in the case of the species here, three drought years coincided with the implementation of the actions. Other factors have also varied that would further mask any response in the annual indices.

Second, delta smelt populations are very small. The ability of the annual indices to show changes in response to actions is compromised due to the inherent lack of precision in sampling and constructing indices of abundance when populations are very small. Unlike salmon and steelhead, the adults of which can be counted with great precision as they migrate upstream, delta smelt are more difficult to count as well as being rare. While this is frustrating, little change in the annual indices over a few years neither invalidates the utility of the actions nor do they demonstrate that the actions are effective. Finally, there were no prior quantified estimates of response to calibrate expectations. Expectations would be better established if the RPA proposals more explicitly quantified the nature and the expected timescale of responses in the target species, and detailed exactly what would be done to assess the validity of those predictions.

RPA RECOMMENDATIONS

The committee concluded that the uncertainties and disagreements surrounding some of the RPA actions could be reduced by some additional activities. In general, the committee recommends that, within the limits the agencies face with respect to human and financial resources, a more-integrated approach to analyzing adverse effects of water operations and potential actions to reduce those effects would be helpful. The approach would include a broader examination of the life cycles of each fish species and where possible, integrating analyses across species. Although there is much general evidence that the profound reduction and altered timing of the delta water supply has been part of the reason for the degradation of these species' habitats, the marginal benefits of beginning to reverse the damage will be difficult to recognize for some time and there is much uncertainty about how to design attempts at the reversal. At this time, the best that can be done is to design a strategy of pumping limitations that uses the best available monitoring data and the best methods of statistical analysis to design an exploratory approach that could include enhanced field measurements to manage the pumping limitations adaptively while minimizing impacts on water users. Such an approach would include a more explicit and transparent consideration of water requirements, despite the variability in environmental conditions and water demand; and population models to evaluate the combined effects of the individual actions.

References

Allen, P. J., and J. J. Cech, Jr. 2007. Age/size effects on juvenile green sturgeon, *Acipenser medirostris*, oxygen consumption, growth, and osmoregulation in saline environments. Environmental Biology of Fishes 79: 211-229.

Anderson, M. J. D. Cacela, D. J. Beltman, S. J. The, M. S. Okihio, D. E. Hinton, N. D. Denslow, and J. T. Zelikoff, Judith. *B*iochemical and toxicopathic biomarkers assessed in smallmouth bass recovered from a polychlorinated biphenyl-contaminated river. Biomarkers 8(5): 371-393.

ASTM (American Society of Testing and Material). 2004. Standard Guide for Application of a Ground-Water Flow Model to a Site-Specific Problem. ASTM D5447-04. Available online at *http://www.astm.org*. Last accessed March 15, 2010.

Baxa, D., T. Kurobe, A. Stover, S. J. The, P. Moyle, and R. P. Hedrick. In progress. Myxosporean infections in the introduced yellowfin goby *Acanthogobiues flavimanus* in Suisun Marsh, California.

Beamesderfer, R. C. P., M. L. Simpson, and G. J. Kopp. 2007. Use of life history information in a population model for Sacramento green sturgeon. Environmental Biology of Fishes 79: 315-337.

Bennett, W. A. 2005. Critical assessment of the delta smelt population in the San Francisco Estuary, California. San Francisco Estuary and Watershed Science 3(2, September): Article 1. Available online at *http://repositories.cdlib.org/jmie/sfews/vol3/iss2/art1*. Last accessed March 15, 2010.

Bennett, W. A., and P. B. Moyle. 1996. Where have all the fishes gone? Interactive factors producing fish declines in the Sacrament-San Joaquin estuary. Pp. 519-541 In J. T. Hollibaugh, editor. San Francisco Bay: The Ecosystem. Washington, D.C.: American Association for the Advancement of Science.

Bouley, P. B., and W. J. Kimmerer. 2006. Ecology of a highly abundant, introduced, cyclopoid copepod in a temperate estuary. Marine Ecology Progress Series 324:219-228.

CDFG (California Department of Fish and Game). 2005. Juvenile steelhead response to summer habitat conditions on the lower American River. Presented by R. Titus and M. Brown. CDFG Stream Evaluation program, Sacramento, CA, April 22.

Clark, G. H. 1929. Sacramento-San Joaquin salmon (*Oncorhynchus tshawytscha*) fishery of California. California Fish and Game Bulletin 17:1-73.

Close, A., W. M. Haneman, J. W. Labadie, D. P. Loucks (chair), J. R. Lund, D. C. McKinney, and J. R. Stedinger. 2003. A Strategic Review of CalSim II and its Use for Water Planning, Management, and Operations in Central California. Oakland, CA: Submitted to the California Bay-Delta Authority Science Program, Association of Bay Governments on 4 Dec. Available online at *http://science.calwater.ca.gov/pdf/CalSim_Review.pdf*. Last accessed March 15, 2010.

Cummins, K., C. Furey, A. Giorgi, S. Lindley, J. Nestler, and J. Shurts. 2008. Listen to the River: An Independent Review of the CVPIA Fisheries Program. Prepared under contract with Circlepoint for the U.S. Bureau of Reclamation and the U.S. Fish and Wildlife Service. Available online at *http://www.cvpiaindependentreview.com/FisheriesReport12_12_08.pdf*. Last accessed March 15, 2010.

Davis, J. A., D. Yee, J. N. Collins, S. E. Schwarzbach, and S. N. Luoma. 2003. Potential for Increased Mercury Accumulation in the Estuary Food Web. San Francisco Estuary and Watershed Science Vol. I. California Bay-Delta Authority Science Program and the John Muir Institute of the Environment.

Deriso, R. 2009. November 13, 2009 Declaration of Dr. Richard B. Deriso. Document 401 In Support of Plaintiffs' Motion for Summary Judgment.

Dugdale, R. E., F. P. Wilkerson, V.E. Hogue, and A. Marchi. 2007. The role of ammonium and nitrate in spring bloom development in San Francisco Bay. Estuarine, Coastal and Shelf Science 73:17-29.

DWR (California Department of Water Resources). 2006. Management of the California water project, State of California, The Resources Agency, 1963 to 2005. Bulletin 132. Available on line at *http://www.water.ca.gov/swpao/bulletin.cfm*. Last accessed March 15, 2010.

DWR. 2009a. The state water project delivery reliability report 2009, State of California, The Resources Agency, Draft, December 2009.

DWR. 2009b. California water plan, State of California, The Resources Agency, 2009 Update. Available online at: *http://www.waterplan.water.ca.gov/*. Last accessed March 15, 2010.

DWR/USBR (California Department of Water Resources and U.S. Bureau of Reclamation). 2004. Peer Review Response, A report by DWR/Reclamation in Reply to the Peer Review of the CalSim-II Model Sponsored by the CALFED Science Program in December 2003.

Edmunds, J. L., K. M. Kuivila, B. E. Cole, and J. E. Cloern. 1999. Do herbicides impair phytoplankton primary production in the Sacramento - San Joaquin River Delta? Pp. 81-88 In D. W. Morganwalp, and H. T. Buxton, editors. U.S. Geological Survey Toxic Substances Hydrology Program - Proceedings of the Technical Meeting, Charleston, South Carolina, March 8-12,1999, v. 2 - Contamination of Hydrologic Systems and Related Ecosystems: U.S. Geological Survey Water-Resources Investigations Report 99-4018B.

Edwards, G. W., K. A. F. Urquhart, and T. L. Tillman. Adult salmon migration monitoring, Suisun Marsh Salinity Control Gates, September–November 1994. Technical Report 50. Sacramento, CA: Interagency Ecological Program for the San Francisco Bay/Delta Estuary.

Erickson, D. L. and J. E. Hightower. 2006. Oceanic distribution and behavior of green sturgeon. Symposium on anadromous sturgeons. J. Munro, D. Hatin, K. McKownet al. Bethesda MD, American Fisheries Society.

Erickson, D. L., and M. A. H. Webb. 2007. Spawning periodicity, spawning migration, and size at maturity of green sturgeon, *Acipenser medirostris*, in the Rogue River, Oregon. Environ. Biol. Fish 79: 255–268.

Erickson, D. L., J. A. North, J. E. Hightower, J. Weber, and L. Lauck. 2002. Movement and habitat use of green sturgeon Acipenser medirostris in the Rogue River, Oregon, USA. Journal of Applied Ichthyology 18: 565-569.

Feyrer, F., M. L. Nobriga, and T. R. Sommer. 2007. Multi-decadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, USA. Canadian Journal of Fisheries and Aquatic Sciences 64:723-734 Available online at: *http://www.iep.ca.gov/AES/FeyrerNobrigaSommer2007.pdf*. Last accessed March 15, 2010.

FWS (Fish and Wildlife Service). 2008. Biological Opinion on Coordinated Operations of the Central Valley Project and State Water Project. Available online at *http://www.fws.gov/sacramento/es/documents/SWP-CVP_OPs_BO_12-15_final_OCR.pdf*. Last accessed March 15, 2010.

Ferreira, I. C., S. K. Tanaka, S. P. Hollinshhead, and J. R. Lund. 2005. Musings on a nodel: CalSim II in California's water community. San Francisco Estuary and Watershed Science 3 (1, March).

Foott, J. S., K. True, and R. Stone. 2006. Histological evaluation and viral survey of juvenile longfin smelt.(*Spirinchus thaleichthys*) and thread fin shad (*Dorosoma petenense*) collected in the Sacramento-San Joaquin River Delta. April-October 2006. Anderson, CA: California Nevada Fish Health Center.

Gartrell, G. 2010. Presentation to the NRC Committee on Sustainable Water and Environmental Management in the California Bay-Delta, Davis, CA. January 26.

Giddings, J. M., L. W. Hall, Jr., and K. R. Solomon. 2000. Ecological risks of diazinon from agricultural use in the Sacramento-San Joaquin River Basins, California. Risk Analysis 20:545-572.

Greene, S. 2008. Declaration of Sheila Greene in response to the July 24 Scheduling Order. Document 402. Pacific Coast Federation of Fishermen's Associations/Institute for Fisheries Resources et al. v. Carlos M. Gutierrez et al.

Grimaldo, L. F., T. Sommer, N. Van Ark, G. Jones, E. Holland, P. Moyle, B. Herbold, and P. Smith. 2009. Factors affecting fish entrainment into massive water diversions in a freshwater tidal estuary: Can fish losses be managed? North American Journal of Fisheries Management 29: 1253-1270.

Gross, E. S., J. R. Koseff, and S. G. Monismith. 1999. Three-dimensional salinity simulations of South San Francisco Bay. Journal of Hydraulic Engineering 125 (11): 1199-1209.

Gross, E. S., M. L. MacWilliams, and W. J. Kimmerer. 2009. Three-dimensional modeling of tidal hydrodynamics in the San Francisco Estuary. San Francisco Estuary and Watershed Science 7(2). Available online at *http://escholarship.org/uc/item/9rv243mg*. Last accessed March 15, 2010.

Hamilton, S. 2010. Presentation to the NRC Committee on Sustainable Water and Environmental Management in the California Bay-Delta. Davis, CA, January 26.

Hanson, C. H. 2009. November 12, 2009. Document 395. Declaration of Charles H. Hanson, Ph.D. In Support of Plaintiffs' Motion for Summary Judgment.

Hare, S. R., N. J. Mantua, and R. C. Francis. 1999. Inverse production regimes: Alaska and West Coast Pacific salmon. Fisheries 24 (1):6-14.

Heublein, J. C., J. T. Kelly, C. E. Crocker, A. P. Klimley, and S. T. Lindley. 2009. Migration of green sturgeon, *Acipenser medirostris*, in the Sacramento River. Environ. Biol. Fish 84:245–258.

Hilborn, R. 2009. November 13, 2009. Document 393. Declaration of Dr. Ray Hilborn In Support of Plaintiff's Motion for Summary Judgment.

Hydrologic Consultants, Inc. 1996. Water Forum Issue Paper Chinook Salmon Mortality Model: Development, Evaluation, and Application as One Tool to Assess the Relative Effects of Alternative Flow and Diversion Scenarios on the Lower American River. Lakewood, CO: Hydrologic Consultants, Inc.

Jassby, A. D., and E. E. Van Nieuwenhuyse. 2006. Low dissolved oxygen in an estuarine channel (San Joaquin River, California): Mechanisms and models based on long-term time series. San Francisco Estuary and Watershed Science 3. Available online at *http://repositories.cdlib.org/jmie/sfews/voI3/iss2/art2*. Last accessed March 15, 2010.

Kimmerer, W. J. 2002. Effects of freshwater flow on abundance of estuarine organisms: Physical effects or trophic linkages? Marine Ecology Progress Series 243:39-55.

Kimmerer, W. J. 2008a. Investigating Particle Transport and Fate in the Sacramento-San Joaquin Delta Using a Particle Tracking Model. San Francisco Estuary and Watershed Science 6(1).

Kimmerer, W. J. 2008b. Losses of Sacramento River Chinook salmon and Delta smelt to entrainment in water diversions in the Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science 6(2). Available online at *http://escholarship.org/uc/item/7v92h6fs*. Last accessed March 15, 2010.

Kimmerer, W. J., and M. L. Nobriga. 2008. Investigating particle transport and fate in the Sacramento-San Joaquin Delta using a particle tracking model. San Francisco Estuary and Watershed Science [online serial] 6(1, February), Article 4. Available online from: *http://repositories.cdlib.org/jmie/sfews/vol6/iss1/art4/*. Last accessed March 15, 2010.

Kjelson, M. A., and P. L. Brandes. 1989. The use of smolt estimates to quantify the effects of habitat changes in salmonid stocks in the Sacramento-San Joaquin Rivers, California. Pp. 100-115 In C. D. Levings, L. B. Holtby, and M. A. Henderson, editors. Proceedings of the National Workshop on Effects of Habitat Alteration on Salmonid Stocks. Special Publication of the Canadian Jorurnal and Aquatic Sciences 105.

Kjelson, M. A., P. F. Raquel, and F. W. Fisher. 1981. Influences of freshwater inflow on Chinook salmon (*Oncorhynchus tshawytscha*) in the Sacramento-San Joaquin Estuary. Pp. 88-108 In P. D. Cross and D. L Williams, editors. Proceedings of the National Symposium on Freshwater Inflow to Estuaries.

Knowles, N., and D. Cayan. 2004. Elevational dependence of projected hydrologic changes in the San Francisco estuary and watershed. Climatic Change 62:319-336.

Kuivila, K. M., and C. G. Foe. 1995. Concentrations, transport and biological effects of dormant spray pesticides in the San Francisco Estuary, California. Env. Tox. Chern. 14:1141-1150.

Kuivila, K. M., and G. E. Moon. 2004. Potential exposure of larval and juvenile delta smelt to dissolved pesticides in the Sacramento-San Joaquin Delta, California. Pp. 229-241 In F. Feryer, L. R. Brown, and J. J. Orsi, editors. Early Life History of Fishes in the San Francisco Estuary and Watershed. American Fisheries Society Symposium 39. Bethesda, MD: American Fisheries Society.

Kynard, B., Parker, E., and T. Parker. 2005. Behavior of early life intervals of Klamath River green sturgeon, *Acipenser medirostris*, with a note on body color. Environmental Biology of Fishes 72(1):85-97.

Lampman, B-H. 1946. The Coming of the Pond Fishes. Portland, OR: Binford and Mort.

Lehman, P. W., G. Boyer, C. Hall, S. Walker, and K. Gehrts. 2005. Distribution and toxicity of a new colonial *Microcystis aeriginosa* bloom in the San Francisco Bay estuary, California. Hydrobiologia 541:87-99.

Lehman, P. W., G. Boyer, M. Satchwell, and S. Walker. 2008. The influence of environmental conditions on the seasonal variation of Microcystis abundance and microcystins concentration in San Francisco Estuary. Hydrobiologica 600: 187-204.

Lehman, P. W., S. J. The, G. L. Boyer, M. L. Nobriga, E. Bass, and C. Hogle. 2010. Initial impacts of *Microcystis aeruginosa* blooms on the aquatic food web in the San Francisco estuary. Hydrobiologia 637:229-248.

Lindley, S. T.; C. B. Grimes, M. S. Mohr, W. Peterson, J. Stein, J. R. Anderson, L. W. Botsford, D. L. Botton, C. A. Busack, T. K. 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. Plamer-Zwahlen, F. B. Schwing, J. Smith, C. Tracy, R. Webb, B. K. Wells, and T. H. Williams. 2009. What caused the Sacramento River fall Chinook stock collapse? National Marine Fisheries Service, Southwest Fisheries Science Center. NOAA_TM_SWFSC-447.

Lindley, S. T., M. M. Moser, D. L. Erickson, M. Belchik, D. W. Welch, E. Rechiski, A. P. Klimley, J. T. Kelly, and J. C. Heublein. 2008. Marine migration of North American green sturgeon. Transactions of the American Fisheries Society 137: 182-194.

Lindley, S. T., R. S. Schick, A. Agrawal, M. Goslin, T. E. Pearson, E. Mora, E, J. J. Anderson, B. P. May, S. Greene, C. Hanson, A. Low, D. R. McEwan, R. B. MacFarlane, C. Swanson, J. G. Williams. 2006. Historical population structure of Central Valley steelhead and its alteration by dams. San Francisco Estuary and Watershed Science Volume 4: Article 3. Available online at *http://repositories.cdlib.org/jmie/sfews/vol4/iss1/art3*. Last accessed March 15, 2010.

Linville, R. G., S. N. Luoma, L. Cutter, and G.A. Cutter. 2002. Increased selenium threat as a result of invasion of the exotic bivalve *Potamocorbula amurensis* into the San Francisco Bay-Delta. Aquatic Toxicology 57(1-2): 51-64.

Manly, B. 2009. November 13, 2009. Document 397. Declaration of Dr. Bryan Manly In Support of Plaintiffs' Motion for Summary Judgment.

Mantua, N. J., and S.R. Hare. 2002. The Pacific decadal oscillation. Journal of Oceangraphy 58:35-44.

Michny, F., and M. Hampton. 1984. Sacramento River Chico Landing to Red Bluff project, 1984, Juvenile salmon study. Sacramento, CA; U.S. Fish and Wildlife Service, Division of Ecological Services.

Mora, E. A., S. T. Lindley, D. L. Erikson, and A. P. Klimley. 2009. Do impassable dams and flow regulation constrain the distribution of green sturgeon in the Sacramento River, California? Journal of Applied Ichthyology 25(s2):39-47.

Moser, M. M., and S. T. Lindley. 2007. Use of Washington Estuaries by Subadult and Adult Green Sturgeon. Environmental Biology of Fishes 79: 243-253.

Moyle, P. 2002. Inland Fishes of California. Second Edition. Berkeley, CA: University of California Press.

Moyle, P. B., P. K. Crain, and K. Whitener. 2007. Patterns of use of a restored California floodplain by alien and native fishes. San Francisco and Estuary Watershed Science 5 (3, July): Article 1. Available at *http://reporitories.cdlib.org/jmie/sfews/vol5/iss3/art1*. Last accessed March 15, 2010.

Moyle, P. B., W. A. Bennett, C. Dahm, J. R. Durand, C. Enright, W. E.Fleenor, W. Kimmerer, and J. R. Lund. 2010. Changing ecosystems: a brief ecological history of the Delta. Report to the State Water Resources Control Board. Available online at *http://www.waterboards.ca.gov/waterrights/ water_issues/programs/bay_delta/deltaflow/docs/intro_delta_history_14feb 2010.pdf.* Last accessed March 15, 2010.

Müller-Solger, A. B., A. D. Jassby, and D. Müller-Navarra. 2002. Nutritional quality of food resources for zooplankton (*Daphnia*) in a tidal freshwater system (Sacramento-San Joaquin River Delta). Limnology and Oceanography 47:1468-1476.

Myrick, C.A, and J. J. Cech, Jr. 2001. Temperature effects on Chinook salmon and steelhead: a review focusing on California's Central Valley populations. Available online at: *http://www.cwemf.orgi*, Bay-Delta Modeling Forum. Last accessed March 15, 2010.

Myrick, C. A., and J. J. Cech, Jr. 2004. Temperature effects on juvenile anadromous salmonids in California's central valley: What don't we know. Reviews in Fish Biology and Fisheries 14:113-123.

NMFS (National Marine Fisheries Service) and FWS (Fish and Wildlife Service). 2010. Coordination between the U.S. Fish and Wildlife Service (FWS) and NOAA's National Marine Fisheries Service (NMFS) throughout the OCAP Consultation Process. Prepared for the NRC Committee on Sustainable Water and Environmental management in the California Bay-Delta. January 15, 2010.

NMFS (National Marine Fisheries Service). 2009. Biological Opinion on the Long-Term Central Valley Project and State Water Project Operations Criteria and Plan. Available on line at *http://swr.nmfs.noaa.gov/ocap.htm.* Last accessed March 15, 2010.

Newman, K. B. 2008. An evaluation of four Sacramento-San Joaquin River Delta juvenile salmon studies. Prepared for CalFed Science Program. Project No. SCI-06-G06-299. March 31. Available online at *http://www.science.calwater.ca.gov/pdf/psp/PSP_2004_final/PSP_CalFed_ FWS_salmon studies_final_033108.pdf*. Last accessed on March 15, 2010.

NRC (National Research Council). 1995. Science and the Endangered Species Act. Washington, D.C.: National Academy Press.

NRC. 1996. Upstream: Salmon and Society in the Pacific Northwest. Washington, D.C.: National Academy Press.

NRC. 2004a. Endangered and Threatened fishes in the Klamath River Basin. Washington, D.C.: The National Academies Press.

NRC. 2004b. Atlantic Salmon in Maine. Washington, D.C.: The National Academies Press.

NRC. 2005. Developing a Research and Restoration Plan for Arctic-Yukon-Kuskokwim (Western Alaska) Salmon. Washington, D.C.: The National Academies Press.

NRC. 2008. Hydrology, Ecology, and Fishes of the Klamath River Basin. Washington, D.C.: The National Academies Press.

Oros, D. R., and I. Werner. 2005. Pyrethroid Insecticides: An analysis of use patterns, distributions, potential toxicity and fate in the Sacramento-San Joaquin Delta and Central Valley. Oakland, CA: San Francisco Estuary Institute.

PBS&J. 2008. Independent Peer Review of USFWS's Draft Effects Analysis for the Operations Criteria and Plan's Biological Opinion. Prepared for the U.S. Fish and Wildlife Service. October 23, 2008. Available on line at *http://www.fws.gov/sacramento/es/documents/BO%20effects%20Peer%20Rev- iew.pdf.* Last accessed March 9, 2010.

Perry, R. W., and J. R. Skalski. 2008. Migration and survival of juvenile Chinook salmon through the Sacramento-San Joaquin River delta during the winter of 2006-2007. Report prepared for the U.S. Fish and Wildlife Service, September 2008.

Perry, R. W. J. R. Skalski, P. L. Brandes, P. T. Sandstrom, A. P. Klimley, A. Ammann, and B. MacFarlane. 2010. Estimating survival and migration route probabilities of juvenile chinook salmon in the Sacramento–San Joaquin River Delta. North American Journal of Fisheries Management 30(1): 142-156.

Roos, M. 1987. Possible changes in California snowmelt patterns. Pp. 141-150 In Proceedings of the Fourth Pacific Climate Workshop, Pacific Grove, CA.

Roos, M. 1991. A trend of decreasing snowmelt runoff in northern California. Pp. 29-36 In Proceedings of the 59th Western Snow Conference, Juneau, AK.

SJRGA (San Joaquin River Group Authority). 2007. 2006 Annual Technical Report: On Implementation and Monitoring of the San Joaquin River Agreement and the Vernalis Adaptive Management Plan.

Sommer, T., C. Annor, R. Baxter, R. Breuer, L. Brown, M. Chotkowski. S. Culberson. F. Feyrer,. M. Gingras. B. Herbold, W. Kimmerer, A. Mueller-Solger, M. Nobriga, and K. Souza. 2007. The collapse of pelagic fishes in the upper San Francisco Estuary. Fisheries 32(6):270-277.

Sommer, T. R., M. I. Nobriga, W. C. Herrell, W. Batham, and W. Kimmerer. 2001. Floodplain rearing of juvenile Chinook salmon: Evidence of enhanced growth and survival. Canadian Journal of Fisheries and Aquatic Sciences 58:325-333.

Sommer, T., K. Reece, F. Mejia, and M. Morbriga. 2009. Delta smelt life-history contingents: a possible upstream rearing strategy. IEP Newsletter 22(1):11-13.

Swanson, C., T. Reid, P. S. Young, and J. J. Cech, Jr. 2000. Comparative environmental tolerances of threatened delta smelt (*Hypomesus transpacificus*) and introduced wakasagi (*H. nipponensis*) in an altered Callifornia estuary. Oecologia 123:384-390.

Tillman, T. L., G. W. Edwards, and K. A. F. Urquhart. 1996. Adult salmon migration during the various operational phases of Suisun Marsh Salinity Control Gates in Montezuma Slough: August-October 1993. Agreement to California Department of Water Resources, Ecological Services Office by California Department of Fish and Game, Bay-Delta and Special Water Projects Division.

Tucker, M. E., C. D. Martin, and P. D. Gaines. 2003. Spatial and temporal distribution of Sacramento pikeminnow and striped bass at the Red Bluff Diversion Complex, including the Research Pumping Plant, Sacramento River, CA: January 1997 – August 1998. Red Bluff Research Pumping Plant Report Series Vol 10. Red Bluff, CA: U.S. Fish and Wildlife Service, Red Bluff.

USBR (U.S. Bureau of Reclamation). 2008. Biological Assessment (BA) of the continued long-term operation of the Central Valley Project (CVP) and State Water Project (SWP), Chapter 2, May 2008.

Van Nieuwenhuyse, E. 2007. Response of summer chlorophyll concentration to reduced total phosphorus concentration in the Rhine River (Netherlands) and the Sacramento-San Joaquin Delta (California. USA). Can. J. Fish. Aquat. Sci. 64: 1529-1542.

Weston, D. P., J. You, and M. J. Lydy. 2004. Distribution and toxicity of sediment-associated pesticides in agriculture-dominated water bodies of California's Central Valley. Environmental Science and Technology 38: 2752-2759.

Weston, D. P, R. W. Holmes, J. You, and M. J. Lydy. 2005. Aquatic toxicity due to residential use of pyrethroid insecticides. Environmental Science and Technology 39: 9778-9784.

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: In press.

Whitener, K., and T. Kennedy. 1999. Evaluation of fisheries relating to floodplain restoration on the Cosumnes River Preserve. Interagency Ecological Program Newsletter 12(3):50-57.

Wilbur, R. 2001. Validation of Dispersion Using the Particle Tracking Model in the Sacramento-San Joaquin Delta, Chapter 4, Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh, 22nd Annual Progress Report, California Department of Water Resources. Available online at *http://modeling.water.ca.gov/delta/reports/annrpt/2001/*. Last accessed on March 15, 2010.

Wilcox, C. 2010. Presentation to the NRC Committee on Sustainable Water and Environmental Management in the California Bay-Delta. Davis, CA, January 26.

Wilkerson, F. P., R. C. Dugdale, V. E. Hogue, and L. A. March. 2006. Phytoplankton blooms and nitrogen productivity in San Francisco Bay. Estuaries and Coasts 29: 401-416.

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. Available online at *http://repositories.cdlib.org/jmie/fews/vol4/iss3/art2*. Last accessed on March 15, 2010.

Williams, R., editor. 2005. Return to the River. Boston, MA: Academic Press.

Appendixes

Appendix A

Committee on Sustainable Water and Environmental Management in the California Bay-Delta

STATEMENT OF TASK

At the request of Congress and the Departments of the Interior and Commerce, a committee of independent experts will be formed to review the scientific basis of actions that have been and could be taken to simultaneously achieve both an environmentally sustainable Bay-Delta and a reliable water supply. In order to balance the need to inform near-term decisions with the need for an integrated view of water and environmental management challenges over the longer-term, the committee will undertake two main projects over a term of two years resulting in two reports.

First, by approximately March 15, 2010, the committee will issue a report focusing on scientific questions, assumptions, and conclusions underlying water-management alternatives in the U.S. Fish and Wildlife Service's (FWS) Biological Opinion on Coordinated Operations of the Central Valley Project and State Water Project (Dec. 15, 2008) and the National Marine Fisheries Service's (NMFS) Biological Opinion on the Long-Term Central Valley Project and State Water Project Operations Criteria and Plan (June 4, 2009). This review will consider the following questions:

- Are there any "reasonable and prudent alternatives" (RPAs), including but not limited to alternatives considered but not adopted by FWS (e.g., potential entrainment index and the delta smelt behavioral model) and NMFS (e.g., bubble-curtain technology and engineering solutions to reduce diversion of emigrating juvenile salmonids to the interior and southern Delta instead of towards the sea), that, based on the best available scientific data and analysis, (1) would have lesser impacts to other water uses as compared to those adopted in the biological opinions, and (2) would provide equal or greater protection for the relevant fish species and their designated critical habitat given the uncertainties involved?

- Are there provisions in the FWS and NMFS biological opinions to resolve potential incompatibilities between the opinions with regard to actions that would benefit one listed species while causing negative impacts on another, including, but not limited to, prescriptions that: (1) provide spring flows in the Delta in dry years primarily to meet water quality and outflow objectives pursuant to Water Board Decision-1641 and conserve upstream storage for summertime cold water pool management for anadromous fish species; and (2) provide fall flows during wet years in the Delta to benefit Delta smelt, while also conserving carryover storage to benefit next year's winter-run cohort of salmon in the event that the next year is dry?
- To the extent that time permits, the committee would consider the effects of other stressors (e.g., pesticides, ammonia discharges, invasive species) on federally listed and other at-risk species in the Bay-Delta. Details of this task are the first item discussed as part of the committee's second report, below, and to the degree that they cannot be addressed in the first report they will be addressed in the second.

Second, in approximately November 2011, the committee will issue a second report on how to most effectively incorporate science and adaptive management concepts into holistic programs for management and restoration of the Bay-Delta. This advice, to the extent possible, should be coordinated in a way that best informs the Bay-Delta Conservation Plan development process. The review will include tasks such as the following:

- Identify the factors that may be contributing to the decline of federally listed species, and as appropriate, other significant at-risk species in the Delta. To the extent practicable, rank the factors contributing to the decline of salmon, steelhead, delta smelt, and green sturgeon in order of their likely impact on the survival and recovery of the species, for the purpose of informing future conservation actions. This task would specifically seek to identify the effects of stressors other than those considered in the biological opinions and their RPAs (e.g., pesticides, ammonia discharges, invasive species) on federally listed and other at-risk species in the Delta, and their effects on baseline conditions. The committee would consider the extent to which addressing stressors other than water exports might result in lesser restrictions on water supply. The committee's review should include existing scientific information, such as that in the NMFS Southwest Fisheries Science Center's paper on decline of Central Valley fall-run Chinook salmon, and products developed through the Pelagic Organism Decline studies (including the National Center for Ecosystem Analysis and Synthesis reviews and analyses that are presently under way).

- Identify future water-supply and delivery options that reflect proper consideration of climate change and compatibility with objectives of maintaining a sustainable Bay-Delta ecosystem. To the extent that water flows through the Delta system contribute to ecosystem structure and functioning, explore flow options that would contribute to sustaining and restoring desired, attainable ecosystem attributes, while providing for urban, industrial, and agricultural uses of tributary, mainstem, and Delta waters, including for drinking water.
- Identify gaps in available scientific information and uncertainties that constrain an ability to identify the factors described above. This part of the activity should take into account the Draft Central Valley Salmon and Steelhead recovery plans (NOAA 2009b), particularly the scientific basis for identification of threats to the species, proposed recovery standards, and the actions identified to achieve recovery.
- Advise, based on scientific information and experience elsewhere, what degree of restoration of the Delta system is likely to be attainable, given adequate resources. Identify metrics that can be used by resource managers to measure progress toward restoration goals.

The specific details of the tasks to be addressed in this second report will likely be refined after consultation among the departments of the Interior and Commerce, Congress, and the National Research Council, considering stakeholder input, and with the goal of building on, rather than duplicating, efforts already being adequately undertaken by others.

Appendix B
Water Science and Technology Board

CLAIRE WELTY, *Chair*, University of Maryland, Baltimore County
YU-PING CHIN, Ohio State University, Columbus
OTTO C. DOERING, Purdue University, West Lafayette, Indiana
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GERALD E. GALLOWAY, JR., University of Maryland, College Park
CHARLES N. HAAS, Drexel University, Philadelphia, Pennsylvania
KENNETH R. HERD, Southwest Florida Water Management District, Brooksville, Florida
JAMES M. HUGHES, Emory University, Atlanta, Georgia
KIMBERLY L. JONES, Howard University, Washington, D.C.
MICHAEL J. MCGUIRE, Michael J. McGuire, Inc., Santa Monica, California
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Appendix C
Ocean Studies Board

DONALD F. BOESCH (Chair), University of Maryland Center for Environmental Science, Cambridge
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Appendix D
Speakers at Committee's Meeting
January 24-29, 2010
University of California, Davis

Ara Azhderian, San Luis and Delta Mendota Water Authority
Barbara Barrigan-Parilla, Restore the Delta
Brett Baker, Delta Resident
Letty Belin, U.S. Department of the Interior
Cheryl Bly-Chester, UC Berkeley
Dan Castleberry, U.S. Fish and Wildlife Service
Jim Costa, U.S. House of Representatives, California-District 20
DeeDee D'Adamo, Office of U.S. Representative Dennis Cardoza, California-District 18
Cliff Dahm, CALFED (Delta Science Program)
Stan Dean, Sacramento Regional County Sanitation District, Director of Policy
Rick Deriso, Inter-American Tropical Tuna Commission
Diana Engle, Larry Walker Associates
Fred Feyrer, Bureau of Reclamation
David Fullerton, Metropolitan Water District of Southern California
Greg Gartrell, Contra Costa Water District
Zeke Grader, Pacific Coast Federation of Fishermen's Association
Cay Goude, U.S. Fish and Wildlife Service
Scott Hamilton, Coalition for a Sustainable Delta
Ann Hayden, Environmental Defense Fund
Bruce Herbold, U.S. Environmental Protection Agency
John Herrick, South Delta Water Agency
Jerry Johns, California Department of Water Resources
Harold Johnson, Pacific Legal Institute
Linda Katehi, University of California, Davis
Jason Larroba, Tehama-Colusa Canal Authority
Tom Lindemuth, Delta Science Center, Big Break
Steve Lindley, National Marine Fisheries Service
Craig Manson, Council for Endangered Species Act Reliability

BJ Miller, Consultant
Ron Milligan, Bureau of Reclamation
Jeffrey Mount, University of California, Davis
Peter B. Moyle, University of California, Davis
Steve Murawski, National Oceanic and Atmospheric Administration
Eligio Nava, Central Valley Hispanic Chamber
Dante John Nemellini, Central Delta Water Agency
Matt Nobriga, California Department of Fish and Game
Doug Obegi, Natural Resources Defense Council
Tim O'Laughlin, O'Laughlin & Paris
Bruce Oppenheim, National Marine Fisheries Service
Richard Pool, Salmon fishing industry
Maria Rea , National Marine Fisheries Service
Rhonda Reed, National Marine Fisheries Service
Mark Renz, Association of California Water Agencies
Spreck Rosekrans, Environmental Defense Fund
Melanie Rowland, NOAA-General Counsel
Patricia Schuffon, Pacific Advocate Program
Jeff Stuart, National Marine Fisheries Service
Nicky Suard, Delta Land and Business owners
Christina Swanson, The Bay Institute
Robert Thornton, Nossaman
Mike Urkov, Tehama-Colusa Canal Authority
Jay Wells, North American Power Sweeping Association
Carl Wilcox, California Department of Fish and Game
Susan William, Pt. Lobos Marine Preserve
Mary Winfree, PoE/USANG
Phil Wyman, Former Central Valley Senator/Assemblyman
Paula Yang, Hmong Sisterhood
Garwin Yip, National Marine Fisheries Service

Appendix E
Biographical Sketches for Members of the Committee on Sustainable Water and Environmental Management in the California Bay-Delta

ROBERT J. HUGGETT*, Chair*, is an independent consultant and professor emeritus and former chair of the Department of Environmental Sciences, Virginia Institute of Marine Sciences at the College of William and Mary, where he was on the faculty for over 20 years. He also served as Professor of Zoology and Vice President for Research and Graduate Studies at Michigan State University from 1997 to 2004. Dr. Huggett is an expert in aquatic biogeochemistry and ecosystem management whose research involved the fate and effects of hazardous substances in aquatic systems. From 1994 to 1997, he was the Assistant Administrator for Research and Development for the U.S. Environmental Protection Agency, where his responsibilities included planning and directing the agency's research program. During his time at the EPA, he served as Vice Chair of the Committee on Environment and Natural Resources and Chair of the Subcommittee on toxic substances and solid wastes, both of the White House Office of Science and Technology Policy. Dr. Huggett founded the EPA Star Competitive Research Grants program and the EPA Star Graduate Fellowship program. He has served on the National Research Council's (NRC) Board on Environmental Studies and Toxicology, the Water Science and Technology Board, and numerous study committees on wide ranging topics. Dr. Huggett earned an M.S. in Marine Chemistry from the Scripps Institution of Oceanography at the University of California at San Diego and completed his Ph.D. in Marine Science at the College of William and Mary.

JAMES J. ANDERSON is a research professor the School of Aquatic and Fisheries Sciences at the University of Washington, where he has been teaching since 1983, and Co-Director of Columbia Basin Research. Prior to joining the faculty at the University of Washington, he did research work at the University of Kyoto in Japan, the National Institute of Oceanography in Indonesia, and

Institute of Oceanographic Sciences in Wormley, UK. Dr. Anderson's research focuses on models of ecological and biological processes from a mechanistic perspective, specifically: (1) migration of organisms, (2) decision processes, and (3) mortality processes. For three decades he has studied the effects of hydrosystems and water resource allocations on salmon and other fish species. He has developed computer models of the migration of juvenile and adult salmon through hydrosystems and heads the DART website, an internet database serving real-time environmental and fisheries data on the Columbia River. His other research interests include mathematical studies in ecosystems, biodemography, toxicology and animal behavior. He has served on a number of regional and national panels and has testified numerous times before Congress on the impacts of hydrosystems on fisheries resources. He received his B.S. and Ph.D. in oceanography from the University of Washington.

MICHAEL E. CAMPANA is Professor of Geosciences at Oregon State University, former Director of its Institute for Water and Watersheds, and Emeritus Professor of Earth and Planetary Sciences at the University of New Mexico. Prior to joining OSU in 2006 he held the Albert J. and Mary Jane Black Chair of Hydrogeology and directed the Water Resources Program at the University of New Mexico and was a research hydrologist at the Desert Research Institute and taught in the University of Nevada-Reno's Hydrologic Sciences Program. He has supervised 70 graduate students. His research and interests include hydrophilanthropy, water resources management and policy, communications, transboundary water resources, hydrogeology, and environmental fluid mechanics, and he has published on a variety of topics. Dr. Campana was a Fulbright Scholar to Belize and a Visiting Scientist at Research Institute for Groundwater (Egypt) and the IAEA in Vienna. Central America and the South Caucasus are the current foci of his international work. He has served on six NRC-NAS committees. Dr. Campana is founder, president, and treasurer of the Ann Campana Judge Foundation (www.acjfoundation.org), a 501(c)(3) charitable foundation that funds and undertakes projects related to water, sanitation, and hygiene (WASH) in Central America. He operates the WaterWired blog and Twitter. He earned a BS in geology from the College of William and Mary and MS and PhD degrees in hydrology from the University of Arizona.

THOMAS DUNNE is a professor in the Donald Bren School of Environmental Science and Management at the University of California at Santa Barbara. He is a hydrologist and a geomorphologist, with research interests that include alluvial processes; field and theoretical studies of drainage basin and hill-slope evolution; sediment transport and floodplain sedimentation; debris flows and sediment budgets of drainage basins. He served as a member of the WSTB Committee on Water Resources Research and Committee on Opportunities in the Hydrologic Sciences and was elected to the National Academy of Sciences in 1988. He has acted as a scientific advisor to the United Nations, the governments of Brazil, Taiwan, Kenya, Spain, the Philippines, Washington, Oregon, several U.S. federal agencies, and The Environmental Defense Fund. He is a recipient of the American Geophysical Union Horton Award. Dr. Dunne holds a B.A. from Cambridge University and a Ph.D. in geography from the Johns Hopkins University.

ALBERT E. GIORGI is president and senior fisheries scientist at BioAnalysts, Inc in Redmond, WA. He has been conducting research on Pacific Northwest salmonid resources since 1982. Prior to 1982, he was a research scientist with NOAA in Seattle, WA. He specializes in fish passage migratory behavior, juvenile salmon survival studies, biological effects of hydroelectric facilities and operation. His research includes the use of radio telemetry, acoustic tags, and PIT-tag technologies. In addition to his research, he acts as a technical analyst and advisor to public agencies and private parties. He regularly teams with structural and hydraulic engineers in the design and evaluation of fishways and fish bypass systems. He served on the NRC Committee on Water Resources Management, Instream Flows, and Salmon Survival in the Columbia River. He received his B.A. and M.A. in biology from Humboldt State University and his Ph.D. in fisheries from the University of Washington.

PATRICIA M. GLIBERT is a professor at the University of Maryland Center for Environmental Science, Horn Point Laboratory, where she has been on the faculty since 1986. Prior to UMD-HPL, she was a postdoctoral scholar and an assistant scientist at the Woods Hole Oceanographic Institution. Her research areas are in transformations and fate of inorganic and organic nitrogen in marine and estuarine systems; ecology of phytoplankton in coastal and oceanic environments; stable isotope techniques; eutrophication and its effects; growth and physiology of marine cyanobacteria and harmful algal bloom species; “top-down” control of nitrogen cycling; primary productivity and its regulation by environmental factors; and impacts of harmful algae on oysters. Her current projects are in the Chesapeake and coastal bays of Maryland, Florida Bay, and the Arabian Sea. She received her B.S. in biology from Skidmore College; M.S. in earth science from the University of New Hampshire; and her Ph.D. in organismal and evolutionary biology from Harvard University.

CHRISTINE A. KLEIN is the Chesterfield Smith Professor of Law at the University of Florida Levin College of Law, where she has been teaching since 2003. She offers courses on natural resources law, environmental law, water law, and property. Previously, she was a member of the faculty of Michigan State University College of Law, where she served as Environmental Law Program Director. From 1989 to 1993, she was an assistant attorney general in the Office of Colorado Attorney General, Natural Resources Section, where she specialized in water rights litigation. She has published widely on a variety of water law and natural resources law topics. She holds a B.A. from Middlebury College, Vermont; a J.D. from the University of Colorado School of Law; and an LL.M. from Columbia University School of Law, New York.

SAMUEL N. LUOMA is a a research professor at the John Muir Institute of the Environment, University of California, Davis and an emeritus Senior Research Hydrologist in the Water Resources Division of the U.S. Geological Survey, where he worked for 34 years. He also holds an appointment as a Scientific Associate at The Natural History Museum, London. Dr. Luoma's research centers on processes the control the fate, bioavailability and effects of contaminants, particularly in the San Francisco Bay-Delta. He served as the first lead on the CALFED Bay-delta program and is the Editor-in-Chief of San Francisco Estuary & Watershed Science. He has helped refine approaches to determine the toxicity of marine and estuarine sediments and developed models that are used in development of water quality standards. His most recent research interests are in environmental implications of nanotechnology and better connecting water science to water policy. He has served multiple times on the EPA's Science Advisory Board Subcommittee on Sediment Quality Criteria and on other NRC committees. Dr. Luoma received his B.S. and M.S. in Zoology from Montana State University, Bozeman, and his Ph.D. in Marine Biology from the University of Hawaii, Honolulu.

MICHAEL J. MCGUIRE is president and founder of Michael J. McGuire, Inc., in Santa Monica, California. He has provided consulting services over the past 18 years to public water utilities and industries in the areas of Safe Drinking Water Act compliance, source water quality protection and water treatment optimization. Prior to his consulting assignments, he was director of water quality and assistant general manager of the Metropolitan Water District of Southern California. His research interests include control of trace contaminants in drinking water; compliance with the Safe Drinking Water Act and all related regulations; occurrence, chemistry, and control of disinfection by-products; and identification and control of tastes and odors in water supplies. He is currently a member of the Water Science and Technology Board of the National Research Council and was selected as a member of the National Academy of Engineering in 2009. Dr. McGuire received his B.S. in civil engineering from the University of Pennsylvania and M.S. and Ph.D. in environmental engineering from Drexel University in Philadelphia.

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