# Sustainable Water and Environmental Management in the California Bay-Delta

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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; National Research Council

# 1

# Introduction

## BACKGROUND[4]

California's San Francisco Bay-Delta Estuary (Figure 1-1) encompasses the deltas of the Sacramento and San Joaquin Rivers as well as the eastern margins of San Francisco Bay. Although the area has been extensively modified over the last century and a half, it remains biologically diverse while simultaneously functioning as a central element in California's water supply system. The Delta system is subject to several forces of change, including seismic activity, land subsidence, sea level rise, and changes in flow magnitudes due to engineering and climate change, which threaten the structural integrity of the Delta and its capacity to function both as an important link in the state's water supply system and as habitat for many species, some of which are threatened and endangered. In anticipation of the need to manage and respond to changes that are likely to beset the Delta, a variety of planning activities have been undertaken. In addition, there have been actions taken under the federal Endangered Species Act (ESA) and companion California statutes, including lawsuits. The net result has been considerable uncertainty and conflict concerning the timing and amount of water that can be diverted from the Delta for agriculture and municipal and industrial purposes and how much water—and of what quality—is needed to protect the Delta ecosystem and its component species.

The Delta is among the most modified deltaic systems in the world (Lund et al. 2010, Kelley 1989). The Sacramento-San Joaquin Delta is an integral part of the water supply delivery system of California. Millions of acres of arid and semi-arid farm lands depend on the Delta for supplies of irrigation water, and approximately 25 million Californians depend on transport of water through the Delta for at least some of their urban water supplies. If California's population grows from the current 37.25 million to nearly 50 million people by 2050, as projected by the California Department of Finance (2007), there likely will be additional water demands even if there continue to be significant reductions in per capita consumptive uses. In addition to supporting these consumptive uses, the Delta provides habitat for animals and plants. Five taxa of fish residing in or migrating through the Delta (one steelhead (*Oncorhynchus mykiss)* population, two populations of Chinook salmon (*Oncorhynchus tshawytscha)*, delta smelt (*Hypomesus transpacificus)*, and green sturgeon (*Acipenser medirostris)*) have been listed as threatened or endangered under the federal Endangered Species Act (ESA) and similarly listed under the California Endangered Species Act. The Delta also supports recreational boating and fishing.

[4] Much of the following material was adapted from NRC 2010 and 2011.

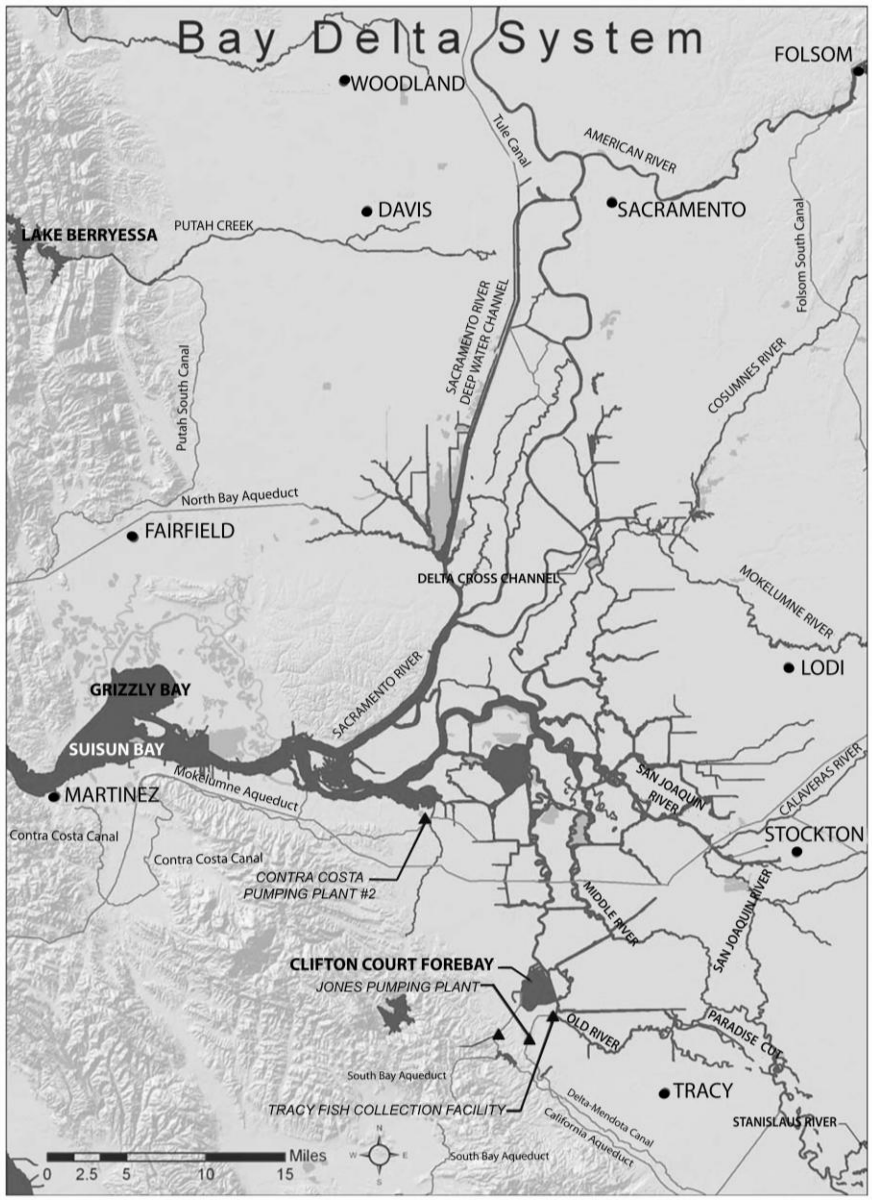


**FIGURE 1-1** The Delta.
SOURCE: Reproduced from NRC 2010, modified from FWS 2008.

The various activities that have taken place in the Delta over recent decades have taken place in a complex and uncertain environment. Those qualities apply to the biophysical environment, including complexities and changes in the hydrologic system, including interactions of altered freshwater discharge regimes with complexities associated with tidal influences, changes in the composition and numbers of many species, variability and changes in precipitation, and changes in the built environment.

They apply also to the human environment, particularly in growth of the human population, complexities and changes in people's livelihoods and lifestyles, political changes, financial and economic changes, changes in people's occupations, changes in technology, and changes in people's understanding of these systems. Uncertainty is inherent in many of the above factors.

The Delta includes the lower reaches of the two most important rivers in California and the eastern estuary and associated waters of San Francisco Bay. Most references to the Delta do not include San Francisco Bay itself—typically, the western extent is around Suisun Bay—but hydrologically, chemically, and biologically, San Francisco Bay is an integral part of the system, and too often is not considered in analysis of the Delta. The Sacramento and San Joaquin Rivers and their tributaries include all of the watersheds that drain to and from the great Central Valley of California's interior. The respective deltas of these rivers merge into a joint delta at the eastern margins of San Francisco Bay and estuary. The Delta proper is a maze of canals and waterways flowing around more than 60 islands that are protected by levees. The islands themselves were historically converted from marshlands as agricultural lands[5] and most of them still are farmed.

Unimpaired inflows of water to the Delta originate in the watersheds of the Sacramento and San Joaquin Rivers. In an average year those flows are estimated to be 40.3 million acre-feet (MAF) or 48.8 percent of California's average annual total water resource of approximately 82.5 MAF. Of the total unimpaired average inflow, 11.4 MAF are diverted upstream of the Delta for agricultural (83.8 percent), urban (15.0 percent), and environmental (1.2 percent) uses. Diversions from the Delta average 6.35 MAF, a little more than one-third of all diversions in the Sacramento-San Joaquin system. Diversions from the Delta are dominated by the exports to the irrigation service areas of the federal Central Valley Project (CVP) and the State Water Project (SWP), which include southern portions of the San Francisco Bay area, the western side of the San Joaquin Valley, and much of southern California. Significant amounts of water are diverted to irrigate Delta lands, and irrigation return flow is discharged into Delta channels. The average yearly outflow from the Delta remaining after diversions equals 22.55 MAF (Lund et al. 2010).

The quantities of water reported above are for an average water year, but hardly any water year in California is average. Water supplies are highly variable from one year to another. Thus, for example, in the Merced River, which drains the watershed including most of Yosemite National Park and is a tributary of the San Joaquin River, the average annual flow is 1.0 MAF. Yet the low flow of record for the Merced River is 150,000 acre feet, only 15 percent of the average flow, whereas the high flow of record is 2.8 MAF, 280 percent of the average flow. The variability in flows, which is characteristic of all of the state's rivers, is largely a function of the interannual variability in amount and patterns of California's Mediterranean climate, which has a wet and a dry season with precipitation falling mainly in the late fall and winter months. In addition, there is considerable variability in the proportion of the precipitation that falls in the mountains as snow, which adds to the variability of the hydrologic regime.

Until recently, planning for water shortage was based on a five-year dry cycle from the 1930s, or on 1977, the driest year of record. However, recent analyses by the Department of Water Resources (2008, 2011) and Hanak (2012) indicate that changes in

[5] Recent historical ecology studies at the San Francisco Bay Institute are revealing that the original Delta landscape was more complex than formerly thought, and had been modified by humans long before the 19th century (http://sfei.org/node/1088).

precipitation resulting from different anticipated climate conditions (see Chapter 4) will affect water availability for all users. Despite statewide conservation efforts, particularly in the urban sector, increasing seasonal restrictions have been applied to diversions, although the total amount of water available for delivery under the terms of SWP and CVP water supply contracts has not decreased. These projects, which export water to regions of the state that have experienced persistent water scarcity for many decades, are particularly important features of the California waterscape.

The CVP withdraws water from the Delta and conveys it southward into the San Joaquin Valley through a system of canals built and operated by the federal Bureau of Reclamation and various municipal and agricultural water-user groups. Most of this water is used for agricultural purposes in the eastern regions of the San Joaquin Valley and the Tulare sub-basin at the southern end of the valley. Some is contracted for domestic use. The SWP withdraws water separately from the Delta and conveys it southward to agricultural users on the west side and at the very southern end of the San Joaquin Valley and subsequently over the Tehachapi Mountains into the conurbation of the South Coast Basin, including Los Angles and San Diego. The SWP supplies domestic water users in southern California (and domestic use in the southern San Francisco Bay Area) as well as Central Valley agriculture in proportions that are determined in any given year by the DWR based orimarily on water in surface storage and anticipated runoff. Available supplies—especially seasonally—have been constrained in recent years by court decisions mandating additional seasonal supplies for environmental purposes.

Changes in hydrologic and physical conditions in the Delta could constrain and threaten the ability of state and federal water managers to continue exporting water in accustomed quantities through the two major projects. This is a concern since the levees, other infrastructure, and the original geomorphology of the Delta are eroding. Lund et al. (2010) identify several factors that today pose significant threats to human uses and ecological attributes the Delta, including: 1) subsidence of the agricultural lands on the Delta islands; 2) changing inflows of water to the Delta, which appear to increase flow variability and may skew flows more in the direction of earlier times in the water year in the future; 3) sea level rise that has been occurring over the last 6,000 years and may accelerate in the future; and 4) earthquakes, which threaten the physical integrity of the entire Delta system. There is a long history of efforts to solve these physical problems as well as persistent problems of flood control and water quality (salinity). Salinity intrusion from the waters of San Francisco Bay now requires a specific allocation of Delta inflows to repel salinity and maintain high qualities of low salinity water at the western margin of the Delta. This management of salinity is accomplishedby monitoring and management of the average position of the contour line of a specified salinity (“$X_2$”)[6]. Controlling salinity requires outflow releases from reservoirs that could be used to satisfy other demands.

Resolution of these problems is complicated by water scarcity generally and because alternative solutions impose differing degrees of scarcity on different groups of stakeholders. There are additional allocation problems that arise from a complex system of public and private water rights and contractual obligations to deliver water from the

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[6] $X_2$ is the salinity isohaline—the contour line—of salinity 2. Often $X_2$ is used as shorthand for the mean position of the contour line of salinity 2, measured in kilometers east of the Golden Gate Bridge (across the mouth of San Francisco Bay), but in this report, $X_2$ refers to the isohaline and not its position.

federal CVP and California's SWP. Some of these rights and obligations conflict and in most years there is insufficient water to support all of them. This underscores the inadequacy of Delta water supplies to meet demands for various consumptive and instream uses as they continue to grow. Surplus water to support any new use or shortfalls in existing uses are unavailable and any change in the hydrologic, ecological, or physical elements in the Delta could reduce supplies further. The risks of change, which could be manifested either by increases in the already substantial intra-seasonal and intra-annual variability or through an absolute reduction in available supplies, underscore the existence of water scarcity and illustrate ways in which such scarcity could be intensified.

In its natural state, the Delta was a highly variable environment. The volume of water inflows changed dramatically from season to season and from year to year. The species that occupied the Delta historically were adapted to variability in flow, quality, and all the various factors they helped to determine. The history of human development of land and water use in the Delta is a history of attempts, with varying degrees of success, to constrain this environmental variability, to reduce environmental uncertainty, and to make the Delta landscape more suitable for farming and as a source of water supplies. It also included the deliberate and accidental introduction of a large number of species of fishes, invertebrates, and plants into the Delta and the surrounding uplands. A full understanding of the historical pervasiveness and persistence of environmental variability underscores the need to use adaptive management[7] in devising future management regimes for the Delta (Healey et al. 2008).

The history of water development and conflict in California focuses in part on the Delta. Beginning with the California gold rush in 1848 early settlers sought to hold back the seasonal influx of water and create agricultural lands. The construction of levees played a central role in this effort, an effort that was threatened in the late 1800s and early 1900s by the movement of hundreds of millions of cubic yards of debris from upstream hydraulic mining that passed through the Delta. Further work throughout the first third of the 1900s helped to stabilize a thriving Delta agriculture (Kelley 1989; Jackson and Patterson 1977). The CVP, begun in the 1930s, and the SWP of the 1960s required conveyance of water from mainstream river channels through the channels and sloughs of the Delta to the extraction points located in the southern Delta from where water is pumped into the Delta-Mendota Canal (CVP) and the California Aqueduct (SWP) for transport south as illustrated in Figure 1-2. Once these projects became operational, there was a need to keep the waters of the Delta fresh, and salinity control became a problem that was decided by the courts (Hundley 2001, Lund et al. 2010).

In addition to serving economic purposes, Delta water has been managed for other purposes. Since the beginning of CVP operations, diversions of water to users outside the Delta have been managed to limit salinity intrusion to local domestic water users in the western margins of the Delta. Additionally, California's constitution (article 10 section 2) requires that the waters of the state be put to "beneficial use;" this criterion is subject to judicial review and determination. The enactment of both state and federal

[7] "Adaptive management is a formal, systematic, and rigorous program of learning from the outcomes of management actions, accommodating change, and thereby improving management" (NRC 2011). Adaptive management and its relevance to the Delta are extensively discussed in that report; the summary reprinted in Appendix B of this report provides a brief version of that discussion.

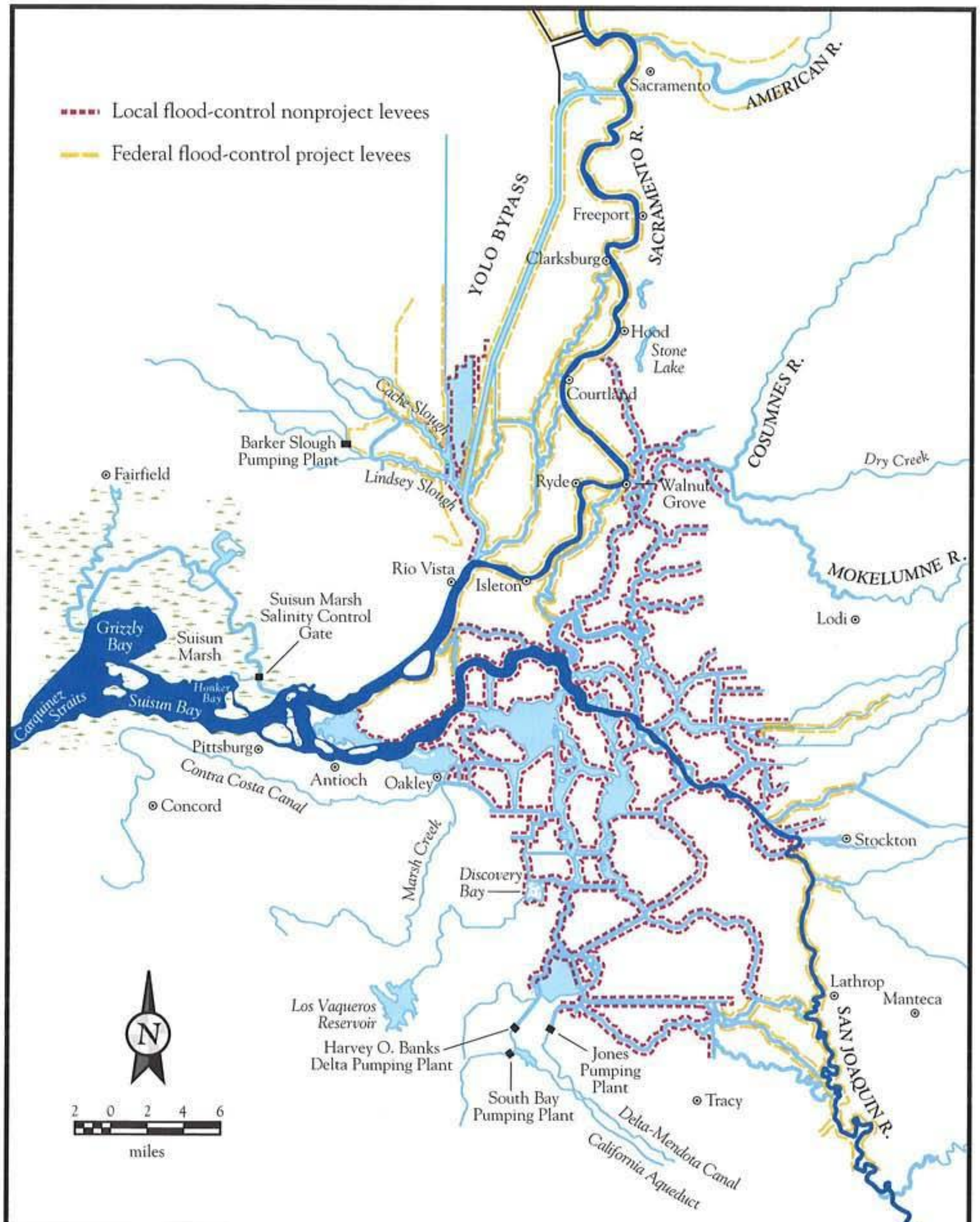


**FIGURE 1-2** Delta Levees, 2006. There are approximately 1100 miles of levees in the Delta.
SOURCE : Lund et al. 2010.

environmental laws, including the California Environmental Quality Act (CEQA) and the National Environmental Policy Act (NEPA) have led to greater allocation of natural and stored water to environmental (in-stream) uses. The importance of environmental uses of water has been reflected further in many state regulatory decisions and, more recently, in judicial interpretations of the federal Endangered Species Act and the California Endangered Species Act. Several species of Delta fishes and anadromous fishes that migrate through the Delta have been listed as threatened and endangered. The courts became involved and specific water allocations followed from court findings. The maze of federal and state laws as well as dozens of stakeholder groups have combined to create a gridlock that sometimes appears penetrable only by state and federal courts (Lund et al. 2010). As a result, most recent reallocation of water has tended to be based on legislative requirements mandating the protection of individual species rather than the optimization of water allocation among all purposes. The legal backdrop is explored further, below.

There have been several efforts to resolve differences, find areas of agreement, and identify solutions to the problems of the Delta and the allocation of the waters that flow through it. These efforts assumed particular urgency as California was beset by severe droughts in the periods 1987-1992 and another late in the first decade of 2000. A collaboration of twenty- five state and federal agencies called the CALFED program was established in 1994; it was unusual in that it had no federal or state legiuslative mandate (Booher and Innes 2010). It had the mission ". . . to improve California's water supply and ecological health of the San Francisco Bay/Sacramento-San Joaquin Delta".[8] State and federal agencies quickly developed a science-based approach to water-quality standards titled *Principles for Agreement on Bay-Delta Standards between the State of California and the Federal Government,* otherwise known as the Bay Delta Accord. State and federal agencies with responsibilities in the Delta and stakeholders engaged in a decade long CALFED process, which resulted in the conclusion that the strategy of relying on the Delta to convey crucial elements of the water supply to California would continue. CALFED would also be used to attain four main goals of water supply reliability, water quality, ecosystem restoration, and enhancing the reliability of the levees (CALFED 2000). CALFED's functions were taken over by the Delta Stewardship Council under California's Delta Reform Act of 2009, as described below. Booher and Innes (2010) provide more detail about the formation, functioning, and evolution of CALFED into the current organizational structure.

The Sacramento-San Joaquin Delta Reform Act of 2009 ("Delta Reform Act") designated the Delta Stewardship Council as "successor" to the California Bay-Delta Authority (the agency that coordinated CALFED), and provided that the Stewardship Council should take over from the Bay-Delta Authority all of its "administrative rights, abilities, obligations, and duties" (California Water Code § 85034(b)). The Delta Reform Act also specified that the newly-created Delta Science Program "shall function as a replacement for, and successor to, the CALFED Science Program" and that the newly-created Delta Independent Science Board "shall replace the CALFED Independent Science Board" (California Water Code § 85280(c)).

The Bay-Delta Accord of 1994[9], and the CALFED process began to unravel around 2003 as environmentalists and water users came to believe that their interests were not being well served and legislators were not satisfied by the CALFED process (Booher and Innes 2010, Lund et al. 2010, Owen 2011). There followed an attempt by the

[8] See http://calwater.ca.gov/calfed/about/index.html

[9] Principles for Agreement on Bay-Delta Standards between the State of California and the Federal Government 1 (Dec. 15, 1994), available at http://www.calwater.ca.gov/content/Documents/library/SFBayDeltaAgreement.pdf.

governor to develop a Delta Vision Strategic Plan or "Delta Vision" with the aid of an independent Blue Ribbon Task Force. The Delta Stewardship Plan ("Delta Plan") resulted from this effort. The Delta Plan is a broad umbrella plan mandated by California Delta Reform Act of 2009 (California Water Code § 85300) to advance the "co-equal goals" of providing a more reliable water supply for California; and "protecting, restoring and enhancing the Delta ecosystem" (California Water Code §§ 85020, 85054). The act requires the Delta Stewardship Council to "develop, adopt, and commence implementation"of the plan by January 1, 2012 and specifies that the membership of Delta Stewardship Council must reflect broad California water interests. Also beginning in mid-decade, federal, state, and local water agencies, state and federal fishery management agencies, environmental organizations, and other parties began work on the Bay Delta Conservation Plan (BDCP), a draft of which was the subject of a recent NRC report (NRC 2011).

Developing the BDCP has been a large and expensive endeavor (NRC 2011). The BDCP is technically a habitat conservation plan under the federal ESA and similarly is a natural community conservation plan under California's Natural Community Conservation Planning Act. "It is intended to obtain long-term authorizations under both the state and federal endangered species statutes for proposed new water operations—primarily an 'isolated conveyance structure,' probably a tunnel, to take water from the northern part of the Delta to the southern thus reducing the need to convey water through the Delta and out of its southern end" (NRC 2011). The initial public (November 2010) draft of the BDCP was reviewed by the NRC (2011);[10] the summary of that report is reprinted in Appendix B.

## WATER RIGHTS IN CALIFORNIA

All of the above activities have taken and continue to take place in a complex legal environment. Below is a description of the legal backdrop surrounding California water.

### Surface Rights

California water law is a unique and complicated system that recognizes both riparian water rights (the system that predominates in the wetter eastern states) and the prior appropriation doctrine (the system that predominates in the arid western states). Cal. Constitution, article 10, § 2. From time to time, the state legislature has tried to diminish the importance of riparian rights to simplify the legal system, but has met with obstacles in the nature of constitutional property rights protections. *See In re* Waters of Long Valley Creek Stream System, 599 P.2d 656 (Cal. 1979).

If there is not enough water to satisfy both riparian and appropriative rights, riparian rights must be satisfied first. Tulare District v. Lindsay-Strathmore District, 45 P.2d 972 (Cal. 1935). However, in some cases, unexercised riparian rights may not enjoy this superior priority. In re Waters of Long Valley Creek Stream System, 599 P.2d 656

[10] The NRC's review focused on the use of science and adaptive management in the draft BDCP.

(Cal. 1979). If surplus water remains, appropriative rights can be satisfied in order of priority.

## Riparian rights

Riparian landowners—those who own property that abuts a natural watercourse—are entitled to make reasonable use of the adjacent water. Riparian uses can be initiated at any time and they are generally not lost through non-use (some older rights may have been lost under the doctrine of prescription, a type of "squatter's right"). However, several important limitations apply to riparian rights: a) *Reasonable use:* The type of use must be "reasonable." The amount of use must also be "reasonable" in light of the purpose to be accomplished and in comparison to the needs of other riparian land owners sharing the same water source; b) *Storage:* The riparian right allows for the diversion of water, but generally not for its storage for later use; c) *Place of use:* Generally, water must be used on the tract of land adjacent to the water source; d) *Shortage:* In times of shortage, all riparians must share the loss through pro-rata reductions (percentage cut-backs often correlate with the percentage of land owned along the common watercourse). The state constitution restricts all water rights to uses that are reasonable and beneficial (Cal. Constitution, article 10, § 2).

Riparian rights are imprecise. Not only must they be cut back in times of shortage, but the determinations of "reasonableness" are made by courts on a case by case, after-the-fact basis when conflicts arise. Thus, it is difficult to know in advance the precise scope of a riparian water right.

## Appropriative water rights

Water rights may be acquired independent of riparian land ownership under the doctrine of prior appropriation. The primary requirement is that the water be placed to "beneficial" use through a "reasonable" means of diversion. Appropriative rights differ from riparian rights in several important respects: a) *Permit process:* Before using water, one must acquire a permit (authorizing the development of a water diversion or project) or a license (confirming the water right) from the State Water Resources Control Board ("State Water Board"). Early appropriations known as "pre-1914" rights are exempt from the permit scheme; b) *Storage:* Appropriative rights may be stored for later use; c) *Place of use:* Water may be used on land apart from the place of diversion, and even transported to other watersheds; d) *Shortage:* Water rights are administered according to the maxim "first in time, first in right." In times of shortage, the most senior priority is satisfied before the next most senior user receives any water. This gives rise to the phenomenon of "paper water rights," under which junior water users may have state-issued water rights that do not yield "wet water" except in years of exceptional precipitation; e) *Non-use:* Because beneficial *use* is the basis and measure of appropriative rights, they can be lost through non-use (Cal. Water Code § 1241). At times, this might create a perverse incentive for users to waste water in order to maintain a historic record of diversion not subject to loss through non-use. To counteract this tendency, 1977 legislation recognizes water conservation as the equivalent to a reasonable beneficial use (Cal. Water Code § 1011(a)).

The priority system provides a measure of predictability lacking under riparian rights. For example, agricultural water users with relatively senior priorities may plant higher priced, permanent crops such as grapes and fruit trees, whereas more junior users might not feel comfortable making an investment in such permanent crops. Despite this relative predictability, appropriative rights can be modified by the State Water Board, which has continuing jurisdiction to modify water permits with conditions to protect other water users and the environment. This authority derives, in part, from California's rigorous interpretation of the ancient Public Trust Doctrine, under which the State has a duty to supervise flowing waters, tidelands, and lakeshores to protect the public interest in resource preservation, fishing, navigation, and commerce (National Audubon Society v. Superior Court of Alpine County, 658 P.2d 709 (Cal.), *cert. denied,* 464 U.S. 977 (1983); State Water Resources Control Board Cases, 136 Cal. App. 4th 674 (2006)).

## Groundwater Rights

There is no comprehensive permit system for the regulation of groundwater in California, although the State Water Board has some (largely untested) authority to restrict "unreasonable use;" local groundwater districts do engage in planning; and the courts can adjudicate groundwater rights (Nelson 2011). Overlying landowners can freely withdraw the percolating groundwater (that is, groundwater that does not flow as an underground stream) beneath their property for reasonable and beneficial use. This right, similar to the surface doctrine of riparianism, is subject to the "correlative" right of other overlying landowners withdrawing from the same source.

## Water Rights for the Environment

California recognizes "recreation" and "preservation and enhancement of fish and wildlife resources" as beneficial uses (Cal. Water Code § 1243). New water rights may not be appropriated for the purpose of "instream flows," as recognized in many western states, because the use of water *within a stream* runs afoul of the traditional requirement of *diverting* water from the streambed. However, since 1991 state law has allowed existing appropriations (originally including a quantified diversion) to be changed to instream flow purposes. As provided by Water Code § 1707(a)(1), "Any person entitled to the use of water, whether based on an appropriative, riparian, or other right, may petition the board . . . for a change of purposes of preserving or enhancing wetlands habitat, fish and wildlife resources, or recreation in, or on, the water." This provision has been used in several cases, including applications in the Sacramento River Basin. California has no comprehensive, statewide instream flow program to supplement these privately-held instream flow water rights.

## WATER RIGHTS AFFECTING THE BAY-DELTA

### Water Contracts

The federal Bureau of Reclamation (operator of the Central Valley Project) and the State Department of Water Resources (operator of the State Water Project) hold appropriative water rights. Like any appropriative rights, they are subject to a variety of permit conditions and other limitations to protect the environment and other water users. These water rights have relatively recent (junior) priorities, generally dating back no earlier than the 1920s. As a result, in drought years, the priority system may limit the water diversions to which the Bureau and the DWR are entitled.

Water contracts add an additional layer of complexity to California's water rights system. By contract, the Bureau and the DWR have agreed to deliver prescribed quantities of their appropriative water rights to numerous water user groups. Whereas most CVP water goes to agricultural users, urban users are the primary recipients of SWP water. The contracts are not uniform, and some have been amended over time. Many, but not all, contain provisions designed to relieve the Bureau and the DWR of their contractual obligations when the agencies' water rights are not fully satisfied due to drought, permit conditions, environmental regulations, or other factors. A typical provision (often found in para. 18(f) of the DWR's contracts) might provide that neither the state nor its agents may be held liable for "any damage, direct or indirect, arising from shortages in the amount of water to be made available for delivery . . . under this contract caused by drought, operation of area of origin statutes, or any other cause beyond its control" (e.g., Tulare Lake Basin Water Storage District v. United States, 49 Fed. Cl. 313 (2001)).

As a result of these factors, there has been uncertainty and dispute over the precise entitlements of those who hold contracts for the delivery of water. The DWR publishes annually a document known as "Table A" that tabulates actual SWP water deliveries as a percentage of 4.133 million acre-feet per year—the maximum amount allocated under SWP contracts (corresponding to the volume of water rights held by the DWR itself for use in the SWP). In its January 2010 draft report, for example, the DWR lists 2009 average annual deliveries as 60 percent of the maximum contract amount. The DWR notes "very significant reductions" in deliveries since 2005. The reductions are attributable, in part, to severe drought, as well as in part to restrictions imposed on the state and federal agencies based on salmon and smelt biological opinions. *See* California Department of Water Resources, Bay-Delta Office, *Draft State Water Project Delivery Reliability Report, 2009*, January 26, 2010.

Some claim that the maximum amount allocated by contract is not the appropriate baseline because it treats limitations inherent in the California water rights system as extraneous interferences with water rights. Rather limitations such as the curtailing of junior water rights, water permit conditions, and the public trust doctrine define the contours of the water right. The California Water Impact Network, for example, asserts that, "The [SWP] project has never in its history delivered [the full contract amount], and has delivered no more than about 2.6 million acre-feet in its peak year." California Water

Impact Network, *California Water Rights Primer: The Monterey Amendments to State Water Project Contracts.*

### The Environment

The Bay-Delta Plan of 2006 and State Water Board Decision 1641 specify Bay-Delta flow requirements. In 2009, California passed a comprehensive package of legislative reforms known as the Sacramento-San Joaquin Delta Reform Act of 2009. Among other things, the new legislation required the State Water Board to develop new flow criteria to protect public trust resources of the Delta ecosystem (Water Code § 85086). On August 3, 2010, the State Water Board issued its final report, *Development of Flow Criteria for the Sacramento-San Joaquin Delta Ecosystem.* The report concluded "[t]he best available science suggests that current flows are insufficient to protect public trust resources" and "[r]estoring environmental variability in the Delta is fundamentally inconsistent with continuing to move large volumes of water through the Delta for export." The recommended flow criteria include "75 percent of unimpaired Delta outflow from January through June; 75 percent of unimpaired Sacramento River inflow from November through June; and 60 percent of unimpaired San Joaquin River inflow from February through June."

The Water Board noted that its recommendations lack binding legal effect unless and until they are implemented through an adjudicative or regulatory proceeding. The recommendations were intended, in part, to inform the development of the Bay Delta Conservation Plan.

## ENVIRONMENTAL CONSIDERATIONS

In addition to water rights, including for the environment, actions in the Delta are affected by federal and state environmental statutes. The federal Endangered Species Act of 1973 and 1988 amendments (16 U.S.C. §§ 1532-1544) has had a far-reaching effect through its application to pumping operations as a result of lawsuits as described above. The act prohibits the taking of species listed as endangered, and by regulation, threatened species are protected as well. It requires federal agencies to make sure their actions, or actions they authorize or fund, are not likely to jeopardize the continued existence of listed species or adversely modify their critical habitats. The agencies do this by consulting with the U.S. Fish and Wildlife Service or the National Marine Fisheries Service if they consider the proposed action might imperil listed species, or sometimes if a court requires them to do so as the result of a lawsuit. The requirements and processes of the Endangered Species Act have been described in detail by the NRC elsewhere (e.g., NRC 1995, 2010a, 2010b).

Other environmental statutes that have relevance to the Delta include the federal Clean Water Act and the National Environmental Policy Act and the state Natural Communities Conservation Planning Act, the California Endangered Species Act, and many provisions of the California Water Code.

## THE CURRENT STUDY

Given the complex backdrop surrounding the California Bay Delta and the importance of this water source to human and ecosystem needs, Congress and the Departments of the Interior and Commerce asked the National Research Council to review the scientific basis of actions that have been taken and that could be taken for California to achieve simultaneously both an environmentally sustainable Bay-Delta ecosystem 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 National Research Council addressed this task over a term of two years, resulting in three reports.

First, this[11] committee issued 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 (December 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, *A Scientific Assessment of Alternatives for Reducing Water Management Effects on Threatened and Endangered Fishes in California's Bay Delta*,[12] considered 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

[11] There were some changes in committee composition after the publication of the first report.
[12] Available through The National Academies Press: http://www.nap.edu/

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, a separate but related NRC panel issued a short report that reviews the initial public draft of the Bay Delta Conservation Plan (BDCP) in terms of the adequacy of its use of science and adaptive management—*A Review of the Use of Science and Adaptive Management in California's Draft Bay Delta Conservation Plan*.[13]

The current report addresses 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 present report includes discussion of topics raised in both of the earlier reports but it is not a recap or re-issue of either of them.

This report addresses tasks such as the following (from the committee's statement of task, see Appendix C):

- 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 Ecological 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 2009), particularly the scientific basis for identification of threats to the

[13] Available through The National Academies Press: http://www.nap.edu/

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 statement of task focuses primarily on science, and does not ask for policy, political, or legal advice. The report organization does not follow the statement of task because the committee concluded the current organization provides a more logical flow. The factors affecting the listed species are discussed in detail in Chapter 3. Future water-supply and delivery options are discussed in Chapters 2, 4, and 5. Scientific uncertainties are discussed throughout the text in Chapters 3 and 4, and the degree of restoration likely to be attainable is in Chapter 4.

The membership of the committee that produced this report overlaps considerably with that of the committee that produced the review of the BDCP, but it is not identical. The committee met three times after the BDCP review was produced; once in Sacramento, California, once in Washington DC., and once in Seattle, WA. At its Sacramento meeting the committee included a public session during which it heard from a variety of speakers (Appendix D). The committee was able to review information received by September, 2011. The report has been reviewed in accordance with NRC procedures: the reviewers are listed in the acknowledgments.

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# Sustainable Water and Environmental Management in the California Bay -Delta

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*OF THE NATIONAL ACADEMIES*

THIS PREPUBLICATION VERSION has been provided to facilitate timely access to the committee's findings. Although the substance of the report is final, editorial changes may be made throughout the text prior to publication. The final report will be available through the National Academies press in 2012.

# Sustainable Water and Environmental Management in the California Bay -Delta

**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

NATIONAL RESEARCH COUNCIL
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# Acknowledgments

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with 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 institution in making its published report as sound as possible and to ensure that the report meets 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 wish to thank the following individuals for their review of this report:

Gregory B. Baecher, University of Maryland
Patrick L. Brezonik, University of Minnesota
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Peter Gleick, Pacific Institute for Studies in Development, Environment, and Security
Daniel Goodman, Montana State University
Jay R. Lund, University of California, Davis
Lynn Scarlett, Resources for the Future

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Michael C. Kavanaugh, Geosyntec Consultants, and Leo M. Eisel, Brown and Caldwell [retired]. Appointed by the National Research Council, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

# Contents

**Appendixes**

# Summary

## INTRODUCTION

California's San Francisco Bay Delta Estuary encompasses the deltas of the Sacramento and San Joaquin Rivers as well as the eastern margins of San Francisco Bay. Extensively modified over the last century and a half, it remains biologically diverse and functions as a central element in California's water supply system. Uncertainties about the future, actions taken under the federal Endangered Species Act (ESA) and companion California statutes, and lawsuits have led to conflict concerning the timing and amount of water that can be diverted from the Delta for agriculture and municipal and industrial purposes and concerning how much water—and of what quality—is needed to protect the Delta ecosystem and its component species.

The Delta is among the most modified deltaic systems in the world. Millions of acres of arid and semi-arid farm lands depend on the Delta for supplies of irrigation water, and approximately 25 million Californians depend on transport of water through the Delta for at least some of their municipal water supplies. Population growth anticipated for the first half of the 21st century is likely to create additional water demands in spite of significant reductions in per capita urban consumptive uses. In addition to supporting these consumptive uses, the Delta provides habitat for animals and plants. The Delta also supports recreational boating and fishing.

Diversions from the Delta are dominated by the exports to the irrigation and urban service areas of the federal Central Valley Project (CVP) and the State Water Project (SWP) service area, which include southern portions of the San Francisco Bay area, the western side of the San Joaquin Valley, and much of southern California. Substantial amounts of water also are diverted upstream for use in the Bay Area and Central Valley cities and farms, and within the Delta itself for local irrigation. Irrigation return flows are discharged upstream and into the Delta itself.Water supplies are highly variable from one year to another.

Despite statewide water conservation efforts, which are particularly pronounced in the urban sector, increasing seasonal restrictions on diversions have been applied, although the total amount of water diverted for explort by SWP and CVP has not decreased. The CVP withdraws water from the Delta and conveys it southward into the San Joaquin Valley through a system of canals built and operated by the federal Bureau of Reclamation and various water user groups. Most of this water is used for agricultural purposes; a small amount is contracted for domestic use. The SWP withdraws water separately from the Delta and conveys it southward to agricultural users on the west side and at the very southern end of the San Joaquin Valley and subsequently over the Tehachapi Mountains into the conurbation of the South Coast Basin. Total available supplies to both CVP and SWP have been constrained in recent years by court decisions restricting diversions because of environmental concerns. In addition, many of the levees have become weak and some of the natural riparian zones of the Delta have been eroded.

Resolution of these problems is complicated by water scarcity generally and because alternative solutions impose differing degrees of scarcity for the uses advocated by different groups of stakeholders. The risk of change in water supplies, which could be manifested either by increases in the already substantial intra-seasonal and intra-annual variability or through an absolute reduction in available supplies, underscores the existence of water scarcity and illustrates ways in which such scarcity could be intensified.

In addition to serving economic purposes, Delta water has been managed for other purposes. Since the beginning of CVP operations, water diversions to users outside the Delta have been managed to reduce the effects of salinity intrusion on local water users in the western margins of the Delta. Additionally, the constitution of California requires that the waters of the state be put to "beneficial use." Although not defined, this criterion is subject to judicial review and determination. The enactment of both state and federal environmental laws has led to increased allocation of natural and stored water to environmental (instream) uses. The importance of environmental uses of water has been reflected further in many state regulatory decisions and, more recently, in judicial interpretations of the federal Endangered Species Act and the California Endangered Species Act that have led to specific water allocations. Five taxa of fish residing in or migrating through the Delta (one steelhead population, two populations of Chinook salmon, delta smelt, and green sturgeon) have been listed as threatened or endangered under the federal Endangered Species Act (ESA) and similarly listed under the California Endangered Species Act. There has not been a comprehensive agreement about how to allocate Delta water to these various purposes.

## The Current Study

Given the complex backdrop surrounding the California Delta and the importance of this water source to human and ecosystem needs, Congress and the Departments of the Interior and Commerce asked the National Research Council to review the scientific basis of actions that have been taken and that could be taken for California to achieve simultaneously both an environmentally sustainable Bay-Delta ecosystem and a reliable water supply. 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 National Research Council addressed this task over a term of more than two years, resulting in three reports.

First, the committee issued a report, *A Scientific Assessment of Alternatives for Reducing Water Management Effects on Threatened and Endangered Fishes in California's Bay Delta*,[1] 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 (December 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). The Executive Summary of this report is in Appendix A.

Second, a separate but related NRC panel issued a short report that reviews the initial public (November 2010) draft of the Bay Delta Conservation Plan (BDCP) in terms of the

[1] Available through The National Academies Press: http://www.nap.edu/

adequacy of its use of science and adaptive management—*A Review of the Use of Science and Adaptive Management in California's Draft Bay Delta Conservation Plan.*[2,3]

This third report addresses the following tasks (the full statement of task is in Appendix C):

- 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.
- 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.
- Identify gaps in available scientific information and uncertainties that constrain an ability to identify the factors described above.
- 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 statement of task focuses primarily on science, and does not ask for policy, political, or legal advice. The report organization does not follow the statement of task because the committee concluded the current organization provides a more logical flow. The factors affecting the listed species are discussed in detail in Chapter 3. Future water-supply and delivery options are discussed in Chapters 2, 4, and 5. Scientific uncertainties are discussed throughout the text in Chapters 3 and 4, and the degree of restoration likely to be attainable is in Chapter 4.

## CHALLENGES AND OPPORTUNITIES

The challenges of managing water and achieving ecological rehabilitation in the Delta are numerous, including the reluctance of many participants to confront the reality that water is scarce; the distribution of water management responsibilities among many agencies and organizations; the suite of environmental factors (stressors) that affect the structure and functioning of the Delta ecosystem, including the many biological and physical changes that have occurred in the Delta; and the lack of detailed understanding of future socioeconomic, climate, biological, and other changes and the consequent lack of ability to plan for them. The following sections discuss the individual challenges; opportunities are reflected in the conclusions and recommendations.

[2] Available through The National Academies Press: http://www.nap.edu/
[3] The summaries of both the recent NRC reports are provided at the end of this report as appendixes.

## Scarcity

Scarcity means that there is simply not a sufficient quantity of some resource or commodity to satisfy all wants for it. Scarcity is a pervasive phenomenon and it is persistent. Water scarcity has always been a fact in California (save, perhaps, for unusually wet periods), and therefore the committee cannot evaluate the items in its charge above without addressing scarcity. The magnitude or intensity of scarcity has grown over time and it continues to grow because demands have grown. There are numerous manifestations of scarcity. For example, legal rulings that require larger allocation of water to support fisheries and environmental flows are a manifestation of scarcity. Concerns about the Delta itself and differing positions about how Delta waters should be allocated are also manifestations of scarcity. The failure to acknowledge scarcity as a fact of life and to craft water plans and policies to address scarcity has made the management of Delta waters far more difficult than it needs to be. The issue of scarcity is discussed in detail in Chapter 2.

## Conclusions and Recommendations

### *California's Two "Co-equal Goals"*

Contemporary planning for water management in the Bay-Delta is directed at two "co-equal goals": providing a more reliable water supply for California and protecting and rehabilitating the Delta ecosystem. There are benefits of having established these goals, but the planning needed to implement these goals has not yet led to clarity on how the inevitable tradeoffs between the goals when water is short will be managed. Thus, the benefits of treating environment and water supply equally cannot be fully realized until some additional conditions are met. The implementation objectives associated with the goals need to be made specific so that when inevitable conflicts between the co-equal goals arise, guidance on how those conflicts should be resolved will be available.

### *Water-Planning Principles and Guidelines for Addressing Scarcity*

The committee recommends consideration of the following principles and guidelines for addressing scarcity in planning:

- Recognize that not all uses of water are always compatible with each other.
- Provide better definition of competing uses; and acknowledge, specify, and account for trade-offs in planning and decision making. The cost of water to users should reflect its scarcity and allocation should be based on analysis that allows for informed decision-making.
- Modify practices that do not reflect the scarcity value of water. The fact of water scarcity does not mean that the state is "running out of water." Although most surface flows have been fully allocated or over-allocated, the state can use a number of tools that optimize the use of existing supplies. As described below there are several tools currently available

for use within existing legal authority. Other tools may require additional legislative authorization.

- Enforce California's constitutional prohibition against non-beneficial, unreasonable, and wasteful water use.
- Protect values recognized under the public trust doctrine.
- Practice water conservation (including improved efficiency and productivity of use).
- Improve groundwater monitoring and regulation in all sectors.
- Consider using water markets to address scarcity. Long-term transfers of water from willing sellers to the state offer a significant opportunity for better management of California's waters consistent with the state constitutional provision. The state could then improve the availability of water for supplemental supplies and instream uses, particularly south of the Delta.

## The Need for Integrated, Coordinated Planning

Water management for the Bay and Delta is distributed among many agencies and organizations, a structure that hinders the development and implementation of an integrated, comprehensive management plan. Recent and current Bay-Delta planning efforts have not yet resulted in a resolution of what is best for the environment or for satisfying anticipated water needs.

### Conclusions and Recommendations

Those engaged in policy making and management should refresh the overall approach to management of water in California that has not been addressed significantly since the late 1960s, when a partial effort was made in the Porter-Cologne Water Quality Act of 1969, which established the State Water Resources Control Board and nine Regional Water Quality Control Boards.

The current organizational structure (or absence of structure), which lacks clear, unambiguous assignments of authorities and responsibilities, makes it difficult to develop and implement a balanced, sustainable plan. The Delta Plan and other efforts under way attempt to satisfy independent legislative enactments, but not the fundamental principles of water management reflected in the Porter-Cologne Act or the state Constitution. For instance, the current version of the Delta Plan deals at length with issues related to financing of various activities. There is no discussion of benefit/cost, efficiency, or priorities for action, all of which are essential parts of effective resource planning.

The committee is not constituted to recommend a specific organizational strategy, but does conclude that the current structure, with distributed authorities and responsibilities, has not been effective and is unlikely to be effective in the future. Issues related to planning and water management are discussed in detail in Chapters 2 and 5.

## Environmental Stressors

Many environmental factors, including water diversions, affect the structure and functioning of biotic communities in the Delta. Although it would be convenient if one or only a few of these factors could be identified as the source of the "problem," or even ranked with some certainty, it is not possible to do that.

Interactions among stressors and between stressors and ecosystem processes are common and can be synergistic or antagonistic. Nutrient enrichment, toxic chemicals and temperature, for example, are affected by physical forces in the system such as hydrologic and hydrodynamic factors. This complicates the interpretation and evaluation of positive, negative, neutral overall effects of any single stressor on the ecosystem and its attributes. Furthermore, species differ in their responses to most types of stress. The result is a complex biological, spatial, and temporal mosaic of impacts from this complex combination of influences.

The ecosystem and its components do not necessarily respond as a unit to most environmental factors. For example, Chinook salmon spend several years at sea and then return to pass through the Delta as adults to spawn; their eggs and young spend time in Delta tributaries before passing through the Delta on their way to the ocean to grow. Returning adult Chinook salmon always die after spawning, so they are not susceptible to chronic environmental stressors, because they die before they can be affected by them. By contrast, delta smelt spend their entire (short) lives in the Delta and so they can be chronically exposed to contaminants in the water. Being smaller and weaker swimmers than salmon, they likely are more susceptible to changes in flow than salmon. In addition, the behaviors, food, distribution in the water column, and physiologies of salmon and smelt are different, so even if they are exposed for a time to the same adverse environmental conditions, their responses to them almost certainly are different.

The above discussion compared only two species, but other species are important as well, including those that are not listed as endangered or threatened. Other species are part of the ecological community and yet they, too, differ in behavior, distribution, physiology, and susceptibility to a wide variety of environmental conditions, including contaminants. There is a complex interplay between key water quality, habitat, and sustainability issues and the drivers affecting them. Furthermore, uncertainties and scientific gaps further compound the problem.

### Conclusions and Recommendation

For all the above reasons, the committee concludes that only a synthetic, integrated, analytical approach to understanding the effects of suites of environmental factors on the ecosystem and its components is likely to provide important insights that can lead to enhancement of the Delta and its species. Nevertheless, the committee has evaluated several stressors in terms of their general importance. Those evaluations are summarized below and presented in detail in Chapter 3.

Given the diverse set of organisms and processes that constitute the Delta ecosystem, the ultimate success of any approach targeted to particular species seems doubtful. In contrast, broad standards established admittedly in the face of some uncertainties, do provide broad protection for the ecosystem, i.e., they adhere to the precautionary principle of doing no harm, but do so at higher water cost, potentially using water that could be used to support economic activity, sanitation, and other needs. Thus, the hard decisions will need to be made about balancing different kinds of risk. These will be matters of policy rather than being the result of a straightforward application of "good science." Exactly because statistical correlations are not adequate to fully explain the responses of aquatic species to either flows or flow pathways, continuing the effort to better understand the processes that control the implications of both flows and flow paths is essential into the future.

Although many stressors are interacting in a complex way, some conclusions are possible with respect to individual stressors.

For migratory salmonids, and probably green sturgeon, dams are significant stressors. They impede passage, cause the loss of spawning and rearing habitat, change the abundance of predators, and affect temperature and flow.

Migrating salmon and steelhead smolts appear to incur substantial levels of mortality during Delta passage. Increasing passage of smolts through Yolo Bypass to reduce Delta passage may be a viable action for Sacramento runs.

Entrainment effects of SWP and CVP pumping are likely large in some years for some species, and thus entrainment acts as an episodic stressor that has a significant adverse effect on delta smelt population dynamics, although it is very difficult to quantify the effects in simple ways.

There is room for improvement in managing volume and timing of flows and flow paths. The committee re-emphasizes the need for life-cycle modeling and a collaborative process to reduce the paralysis that can occur from the adversarial use of models and to encourage cross-comparisons and cross-fertilization. The recent increase in life-cycle modeling for both delta smelt and salmonids is an encouraging development.

The committee has not analyzed the benefits and disadvantages of an isolated conveyance facility, because not enough specific information was available about it, and we make no recommendation with respect to its adoption as a major part of water management in the Delta. However, the committee does recommend that before a decision is made whether to construct such a facility and in what form, the sizing of the facility, its location, and the diversion design and operation, including the role of current diversions, should be analyzed as part of any integrated Delta plan, and compared to alternative water management options, including current operations.

Changes in nutrient loads and concentrations in the Delta and Bay, especially those for nitrogen and phosphorus, are stressors of increasing concern from water quality and food web perspectives. Toxic pollutants such as selenium also appear to be significant stressors, especially for sturgeon, with San Francisco Bay and the San Joaquin River being the areas of greatest concern.

The stressors also interact with each other and with changes in salinity, turbidity, and freshwater discharges resulting from hydrologic changes in the Delta and its tributaries, changes that have been attributed to water exports, changes in land use, and changes in the morphology of the Delta. The latter factor, caused by canalization and the abundance of hardened structures that also have eliminated tidal wetlands, has affected delta smelt by changing their aquatic habitats. Support for better understanding the processes that link flows, habitat structure and habitat characteristics such as salinity, turbidity and temperature should remain a high priority. Reductions in outflow caused by diversions tend to reduce the abundance of some Delta and Bay organisms.

Introduced species have caused dramatic changes in habitat, prey, and predators of the listed fish species in the Delta. Introductions of nonnative species will continue into the future as management controls that substantially reduce risk are difficult and expensive to implement. Changes in human activities and climate change could exacerbate the frequency of invasions and persistence of invading organisms in the future. Early detection through monitoring is useful in order to prepare for likely changes to the ecosystem.

Largely because negative effects of hatcheries are difficult to observe, the committee cannot reach a conclusion as to whether and how much hatcheries have contributed to the decline in wild populations of salmonids in the Central Valley. The committee judges that adoption of recent conservation guidelines under a unified hatchery management plan will reduce (but not eliminate) risk to wild populations from hatcheries, and probably represents the most viable option for maintaining populations of salmonids in the Central Valley unless or until other methods are found to increase the productivity of wild populations.

Coastal ocean productivity is one of the most significant factors determining the ocean survival of juvenile salmon and the number of adult salmon that return to spawn. When ocean conditions are unfavorable for salmon and steelhead, those effects can be partially ameliorated by increasing the diversity of wild and hatchery salmon ocean entrance timing.

Currently, disease does not appear to be a significant stressor factor for juvenile or adult salmon or other fish species in the Delta.

Consideration of the large number of stressors and their effects and interactions leads to the conclusion that efforts to eliminate any one stressor are unlikely to reverse declines in the listed species. Opportunities exist to mitigate or reverse the effects of many of the above stressors. To make it more likely that any actions to rehabilitate the ecosystem are cost-effective, continued effects analyses, modeling, and monitoring will be needed.

## Environmental Change and Ecosystem Rehabilitation

Climate change is one of the most challenging and important issues confronting the management and rehabilitation of the Delta ecosystem. Changes in climate are expected to have profound effects on the physical and ecological structure of the Delta as well as the nature of water issues in the California. The cascading effects of climate change begin with increasing air temperature, which over the 50-year planning horizon of the Delta's BDCP, is predicted to increase between 1° and 3°C. As a result, snowmelt will occur earlier than currently, and more winter precipitation will fall as rain, as opposed to snow, than currently. The changes are expected to have large effects on temporal and spatial hydrologic patterns even if the average annual precipitation volume did not change.

In addition to changes in hydrologic patterns, sea level also is expected to rise as a result of climate warming. Sea-level rise would interact in complex ways with altered hydrologic patterns and the effects are not easy to predict. However, it does seem clear that the combination of sea-level rise and altered hydrologic patterns would increase the risk to Delta infrastructure, such as levees.

Increased temperature likely would reduce the distribution of salmonids in the Central Valley. In many parts of their range they encounter summer temperatures near the lethal limit for them. The frequency and duration of such temperatures is expected to increase, and their effects likely would be exacerbated by changes in hydrologic patterns.

If the climate projections are correct, more frequent extreme events will increase the need for Central Valley water for both environmental and human uses. In this case, managers may be asked to consider hard choices. While such the predicted changes may not come to pass, the committee encourages continued critical and comprehensive studies of the full range of future possibilities and how to adapt to climate change. The implications of climate change for the Delta and for environmental rehabilitation and water supplies are discussed in detail in Chapter 4.

## Conclusions and Recommendations

Habitat loss and alterations, climate change, and unpredictable levee failure pose significant challenges in the formulation of plans for sustaining the Bay and Delta ecosystem. However, there are many opportunities to steer the future evolution of the ecosystem by addressing future challenges.

Extensive physical changes in the Delta ecosystem and the tributary watersheds, and continuously evolving changes, such as land subsidence in the Delta islands, will not allow the re-creation of habitat as it once existed in the pre-disturbance state. Delta restoration programs will need to balance consideration of an ecosystem approach with the ESA's emphasis on individual species. Programs will need to focus on the interaction of biological, structural, and physical aspects of habitats and how they may change in the future. Even without ESA-listed species, there still would be a need to guide the ecosystem toward desirable states.

Assessments suggest that many species will be affected by changes in the pattern and types of precipitation. Changes already are being observed. Projected increases in the mean sea level and the extremes have the potential to increase the frequency of levee failures and inundation of islands, in part because the land inside the levees continues to subside through oxidation of peat. Sea level rise also has the potential to enhance saltwater intrusion and alterwater quality.

Planning and evaluation of future environmental and economic scenarios will need to address the uncertainties in projections, integrated analysis, and the development of risk management strategies (e.g., adaptive management). The uncertainties are higher about the environmental aspects of operations than about the reliability aspects of water deliveries. Climate change implications and the continued increase in water demands in the Bay-Delta system and beyond will exacerbate the competition for water and limit the ability to meet the co-equal goals.

Future planning should include the development of a climate-change-based risk model and analysis that incorporates data on the actual changes in Delta conditions as well as alternative future climate scenarios and their probability. The real challenge is deciding how to adapt to a new environment. Strategies to deal with the expected and unprecedented changes will need to consider many factors, including targeted demand management, increased surface and groundwater storage consistent with minimizing environmental impacts, enhanced flexibility in the water management system through operational optimization and maximum flexibility for moving water, and developing an understanding of and establishing environmental flows for the ecosystem.

The instability and interdependence of levees—failure of one levee can affect others—are likely to be major issues for achieving any measure of water-supply reliability or ecosystem rehabilitation. Continuing the status quo of improving levees will not always be the most environmentally sustainable or economically defensible response in the years ahead. Changes in the levee system, and even removal or modification of some levees, could be good for at least parts of the ecosystem.

Resource managers dealing with the Delta will need to determine the degree of "restoration" achievable through intervention and adaptation. The Delta as it existed before large-scale alteration by humans cannot be recreated. With respect to species, habitats, productivity and other aspects, the future Delta will still be a functioning ecosystem but different from the one that exists today. However, there is a considerable capacity to guide the direction of the Delta towards a more desirable future by focusing on a functioning resilient ecosystem without abandoning individual efforts to protect individual native species. Achieving the above will require extensive, thoughtful, and transparent planning. That planning will need to include finding ways to reconcile diverse interests without pretending that everybody can have what they want.

## The Role of Science and Planning: A Path Forward

Science is necessary to inform actions and proposals related to restorations of all kinds. However, science alone does not provide the entire prioritized, integrated analysis that the committee recommends. For instance, science can provide information on options regarding the control of ammonium to maintain an adequate food supply for fish, on the consequences of different schedules for investment in Delta levees to protect agriculture, and on the degree of effectiveness of future diversion restrictions to protect salmon in the mainstream of the Sacramento River. However, science cannot decide which choice is the best policy. That requires societal and political considerations as well and information on potential benefits and costs. Using the best science is only part of what is needed to resolve the competing interests. The role of science, including its limitations, is discussed in detail in Chapter 5.

## Conclusions and Recommendations

The committee concludes that the lack of explicitly integrated comprehensive environmental and water planning and management results in decision-making that is inadequate to meet the Delta's and state's diverse needs, including environmental and ecological conditions in the Delta. In addition, the lack of integrated, comprehensive planning has hindered the conduct of science and its usefulness in decision making. Lack of transparency exacerbates these matters and erodes public trust.

The committee recommends California undertake a comprehensive review of its water planning and management functioning, and design modifications to existing responsibilities and organizations that will anticipate future needs including those identified in this report. These needs include dealing with scarcity, balanced consideration of all statewide water use practices and water-engineering alternatives; and adaptive management that can adjust to changing conditions. The result should be that regions such as the Delta can be effective partners in a coordinated statewide effort.

The committee makes no recommendation of any specific organizational strategy for institutional changes. Any strategy should incorporate the public's desires and achieve the public's trust while allowing for decisions to be made.

Delta conditions identified in previous chapters indicate that scarcity of water for all needs will become severe. While more effective planning is being developed, the state will need to use its water resources efficiently and productively. A variety of tools are available, including demand-side management (conservation, including more-efficient and more-productive water use) and supply-side management (water transfers conducted by the state or within a new central planning function, new sources of supply, more-integrated management of gound- and surfacewater, enforcement of the constitutional reasonable and beneficial use limitations and invocation of the state Public Trust Doctrine to reconsider past allocation decisions). Thus reliability-dependent users (urban, industrial and agricultural) would have some long-term confidence that supplies will be more predictable. As part of its oversight of such transfers, the state needs to insure that necessary instream flow levels are maintained. Continued, substantial investments in monitoring, modeling, and other research to inform policy choices will be essential.