Introduction

Report purpose

This report presents a science-based assessment of the health of San Francisco Bay. The authors reviewed available data and developed methods for evaluating the status and trends of the Bay's vital signs. By providing all interested parties with these results, the broader community can consider whether resource managers, regulators, and citizens are taking enough of the right actions to protect the Bay. With this assessment, the Estuary Partnership will begin to report on the state of the Bay on a regular basis, with the goal of educating the public and helping scientists and managers make decisions about how to best allocate resources to protect and restore the Bay.

Background

San Francisco Bay is an extraordinary natural resource that contributes to our region's economy and quality of life. Its iconic presence attracts tourists from around the globe who contribute to a thriving Bay Area economy. One of the world's great natural harbors, it has played a defining role in the history of the United States and is the aesthetic, economic, and ecological centerpiece of America's fourth largest metropolitan area. It is also an estuary—a body of water where fresh water from rivers meets salt water from the ocean.

JUDY IRVING

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State, local, and federal water projects divert fresh water from the rivers flowing into this Estuary to serve 30 million people with some portion of their drinking water, and to irrigate four million acres of agricultural land. At the same time Bay Area residents rely on the Bay to absorb over 500 million gallons of treated wastewater each day and vast quantities of urban floodwaters during rainstorms. Each year we mine two million tons of sand from the Bay for construction, and 65,000 cubic yards of oyster shell deposits for calcium supplements.

The Bay delivers these benefits while providing habitat for fish, birds, and other wildlife, recreational opportunities for residents, and support for an over $34 billion maritime industry.[1] Two-thirds of the state's salmon pass through the Bay, a commercial fishery continues for Pacific herring, and nearly half of the Pacific coast waterfowl and shorebirds depend upon the Bay and its mudflats for sustenance during their migrations.

Considering all of these benefits the Bay provides, it is not surprising that in a recent poll, 92 percent of Bay Area voters agreed with the statement that "it is important for the region's economy to have a clean, healthy and vibrant San Francisco Bay."[2] This desire is reflected in the largest, most ambitious restoration project now taking place on the West Coast, the restoration of 15,100 acres of former solar evaporation salt ponds in the South Bay to tidal marsh habitat and managed ponds (see "Salt Ponds to Shorebird Heaven," pages 10–11).

A BRIEF HISTORY OF EFFORTS TO EVALUATE THE STATE OF THE BAY

The Bay was not always appreciated as a valuable resource. For the century after the Gold Rush it was often treated as an enemy of progress, to be conquered by draining and filling, or as a convenient dump for wastes.

In retrospect, we realize that people did not understand how their actions were affecting the Bay or how their quality of life and the economy were connected to it. Our actions resulted in a decline in ecological health, as indicated by fish kills, waste buildup, and the stench at the shoreline. As late as the 1950s, South Bay marshes were so polluted that the local atmosphere would turn silver coins in one's pocket brownish-grey in a matter of minutes.[3]

In response, new legal frameworks emerged to control pollution (Water Pollution Control Act of 1948; amendments in 1956, 1965, and the Porter Cologne Act of 1969). And prompted by the work of citizen activists Sylvia McLaughlin, Esther Gulick, and Kay Kerr, the McAteer-Petris Act was adopted in 1965 establishing the Bay Conservation and Development Commission and ending the unregulated filling of the Bay. Efforts like these, by citizen activists and by concerned regulators and resource managers, led to attempts to evaluate the state of the Bay so that actions could be taken to protect and improve it.

In 1987, Congress established the National Estuary Program by amending the Clean Water Act (33 USC 1330) to further improve the chemical, physical, and biological integrity of the nation's estuaries. San Francisco Bay was identified as an Estuary of National Significance under this program, and from 1987 to 1993, hundreds of stakeholders worked together to craft a Comprehensive Conservation and Management Plan (CCMP) for the Estuary using the existing base of high quality science. In that process, community leaders, scientists, resource managers, regulatory agencies, and citizen activists came together to promote the goal of achieving and maintaining an ecologically diverse and productive natural estuarine system.[4] The CCMP, approved in 1993 by the Governor and the US EPA (updated in 2007), set forth a list of 145 actions to preserve, enhance, and restore the Estuary's ecosystem.

As part of the development of the CCMP, the first *State of the Estuary* report (1992) concluded that the Estuary "has some very real and significant environmental problems" that are "documented by research and monitoring data." The report noted that "many of the Estuary's problems are getting worse, while only a few have improved" and that "additional actions are needed to solve them."[5]

The report identified the major stressors affecting the health of the Bay as

- intensified land use (and the resulting conversion of natural land cover to human uses)
- diversions of fresh water and altered flow regimes
- increased pollutants
- increased dredging and waterway modification

The CCMP was structured to address these stressors, with a diverse array of actions for management agencies to take.

Since the 1992 *State of the Estuary* report was published, management efforts to address the problems have continued and expanded. Progress toward implementing these efforts has been reported every other year at State of the Estuary conferences, and in reports summarizing those conference presentations as well as the status of species of concern, fish populations, and flows. In addition, several monitoring and assessment programs have provided information about the Bay's resources and whether our investments in environmental protection and restoration are achieving desired outcomes. These programs have heightened our appreciation of the complexity of the ecosystem and how its health is a product of both human and natural influences.[6]

PETER BAYE

In 1996, The Bay Institute (TBI), Environmental Defense Fund, and the UC Berkeley Center for Sustainable Resources issued a report describing a framework for developing San Francisco Bay-specific health indicators. In 2003 and 2005, TBI developed and issued an *Ecological Scorecard* for San Francisco Bay, extremely valuable pilot efforts to develop and evaluate science-based ecological indicators in a manner accessible to the public. Many indicators in this report build on TBI's efforts.

The Estuary Partnership then continued to develop ecological indicators in collaboration with TBI and other partners. With support from the Department of Water Resources from 2008 to 2010, a number of potential indicators, identified in previous assessments, were screened using a set of established criteria. The indicators were then used by this report's authors—scientists from the San Francisco Estuary Institute, The Bay Institute, PRBO Conservation Science, and the Center for Ecosystem Management and Restoration—to prepare this report. This report thus builds upon previous plans and assessments to evaluate the health of San Francisco Bay. It is also based on guidance documents from the National Academy of Sciences and the US EPA Science Advisory Board (see timeline, below).

The goal of this report is to transform scientific measurements into assessments of "health" or "integrity." The methods and judgments applied herein are fully transparent and documented, and the data used are all publicly available. Interested readers can review the appendix to this report to understand the data and methods used to develop all aspects of the analyses. Continued review and refinement of the data and the conclusions presented here will give the citizens and resource managers of our region an increasingly accurate assessment of the overall health of San Francisco Bay.

How do we assess the state of the Bay?

How do we determine if the Bay is healthy? How do we decide if the goals of the Clean Water Act to "protect and restore the chemical, physical, and biological integrity" of the Bay are being met? The authors drew upon science and public policy to make informed judgments, first by identifying the attributes of the Bay that comprise its integrity and reflect its health. With those attributes identified, we then selected indicators of these attributes using meaningful and systematic criteria. In the third step we determined benchmarks against which to compare the measurements of the indicators in order to evaluate the status of the attributes and judge the Bay's health.

Milestones in the development of health indicators for San Francisco Bay

February 1986
"The Modification of an Estuary." Nichols et al, *Science*

1986
Management Conference created per §320 of Clean Water Act

1990–92
Six *Status and Trends Reports* completed

June 1992
State of the Estuary report

November 1993
CCMP adopted

1995
Baylands Habitat Goals process begins

1996
UC Berkeley: *Restoration of the San Francisco Bay-Delta-River Ecosystem: Choosing Indicators of Ecological Integrity*

1998
First *Pulse of the Estuary* (1993–1998) (SFEI)

STEP 1: Identify key attributes, and their conceptual relationship

Following the guidance of US EPA's Science Advisory Board, the key attributes of an estuary are

- water (both the amount of water and its chemical quality)
- physical habitats
- ecological processes such as the cycling of nutrients and predator-prey interactions that are part of the food web
- living resources

These attributes are interacting parts of an ecosystem that influence each other (directly and indirectly), and so affect the environmental goods and services upon which humans depend. Humans are also an integral part of this ecosystem, and exert a variety of influences on the Bay's different attributes (Figure 1, page 8). Humans can also reduce some of their impacts on the ecosystem. To evaluate the effectiveness of some of the actions taken to reduce impacts, the report also assesses indicators of stewardship.

In a healthy Bay:

- Water should not be toxic to living creatures, nor cause these animals to be toxic to humans.
- Water should be of good enough quality to allow for recreation in and on the Bay.
- Seasonal freshwater flows are adequate to support native plants and animals and the ecological processes driven by flows.
- Habitats should include a diverse and well-distributed array of key components such as wetlands, waters of varying salinity, sediments, and sea grass beds that support valued ecosystem components.
- Ecological processes should support vibrant food webs, replenish sediment in the landscape, cycle nutrients, mix fresh and salt water, and flush wastes.
- Living resources should include robust and resilient populations of diverse native species groups, including birds, fish, mammals, invertebrates, and plankton.
- Stewardship efforts should include individual and community actions that reduce adverse impacts on the ecosystem. Stewardship includes actions by volunteers as well as regulators, managers, and the regulated community, such as cities, counties, and industry.

STEP 2: Select indicators

With these attributes of health defined, our next step was to identify measurable indicators. Based upon the work of the National Academy of Sciences and others, a set of criteria was used to select valuable indicators (Table 1).[7] Indicators are valuable if they are meaningful and relevant to the public, consistent with scientific understanding of the ecosystem, and can be measured with existing, reliable data. Our indicators also

1999 Ecological indicators concepts presented at State of the Estuary Conference

2000 National Academy of Sciences: *Ecological Indicators for the Nation*

2001 Updated ecological indicators concepts presented at State of the Estuary Conference

2002 EPA Science Advisory Board: *A Framework for Assessing and Reporting on Ecological Condition*

SFEP initiates Bay health indicators

2003 *Ecological Scorecard* published by The Bay Institute

2004 SFEP: *Development of Environmental Indicators of the Condition of San Francisco Estuary* (prepared by SFEI)

January 26, 2005 Indicator workshop (Battelle Memorial Institute)

2005 The Bay Institute updates the *Ecological Scorecard*

2006 National Estuary Program issues coastal condition report

2007 SFEP and partners begin screening ecological health indicators (supported by DWR)

2008 *The State of the Bay–Delta Science* report

June 2009 Begin State of the Bay report

2010 *Subtidal Habitat Goals Report* completed

2011 *Upland Habitat Goals Report* to be completed

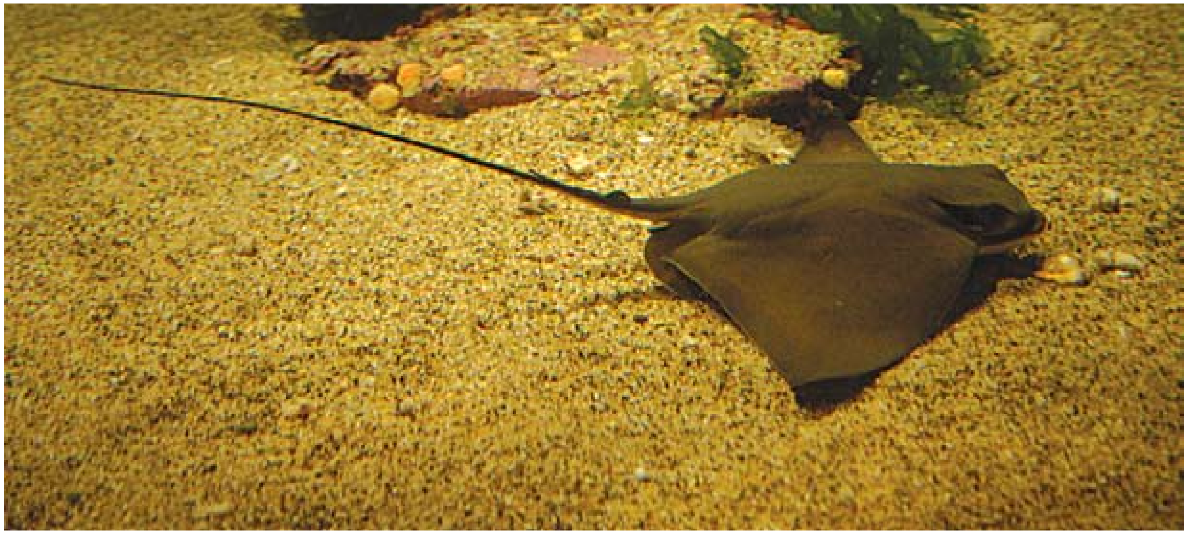
Table 1. State of the Bay 2011 Health Indicators*

ATTRIBUTE	INDICATOR	BENCHMARKS
WATER		
Quality	• Safe for aquatic life? Toxicity to the animal and plant species that live in or depend upon the Bay (excluding humans), including phytoplankton, algae, zooplankton, macroinvertebrates, fish, aquatic birds, and marine mammals	Goals are standards set by the State of California for concentrations of chemical pollutants in water, methylmercury concentrations in the food web, and the toxicity of Bay waters and sediments in laboratory tests.
	• Safe to eat Bay fish: Contamination of fish	Goals are established by the State of California to protect public health (OEHHA).
	• Safe for humans to swim: Concentrations of bacteria indicating fecal contamination	Goals are standards for bacteria and fecal contamination established by the California Department of Public Health.
Quantity	• Amounts, timing, and patterns of freshwater inflow, variability	Benchmarks are based on the State Water Resources Control Board's conclusion that protection of public trust resources requires 75 percent of unimpaired runoff from the Sacramento–San Joaquin watershed flow into the San Francisco Bay during the winter and spring.
HABITAT		
Estuarine open water	• Quantity and quantity of seasonal low-salinity habitat	The benchmark for high quality open water habitat is that X2 (salinity is 2 parts per thousand) be located less than 65 kilometers from the Golden Gate for more than 100 days from February through June.
Baylands (tidal marsh and tidal flat)	• Regional extent	The 1999 *Baylands Ecosystem Habitat Goals Report* established the goal of restoring 100,000 wetland acres. The benchmark for tidal flats is half of the historical extent, or 30,000 acres.
	• Size of existing parcels (patch size)	The benchmark is ±25 percent of the historical patch size for each size category.
	• Physical/biological condition	The benchmark is the physical structure score for North Coast marshes using the California Rapid Assessment Method (CRAM).
Watersheds	• Width of riparian areas	The benchmark is a percent of the historical riparian width distribution.
	• Stream habitat condition	The benchmark is a CRAM score of 75 percent of the reference stream value.
	• Stream biological integrity	The benchmark is that 75 percent of watershed stream assessments should have excellent or good health as evaluated using the Benthic Macroinvertebrate Index (BMI).

*Detailed information on data sources and indicator calculations are provided in the Technical Appendix at www.sfestuary.org.

ATTRIBUTE	INDICATOR	BENCHMARKS
LIVING RESOURCES		
Invertebrates	• Shrimp and crab abundance • Shrimp distribution • Shrimp and crab species composition	The benchmark is the average for comparable data from 1980–89; for species composition, the benchmark is 85 percent native species.
Fish	• Abundance, diversity, species composition, and distribution of the Bay's fish community	The benchmark is the average for comparable data from 1980–89; for species composition, the benchmark is 85 percent native species.
Birds	• Abundance of breeding tidal marsh birds	The benchmark is the upper quartile value of birds observed in mature tidal marsh, or an average of 0.93 birds per acre across Bay regions.
	• Tidal marsh bird reproductive success	The benchmark is a nest success rate of 20 percent, the minimum needed to sustain populations.
	• Heron/egret nest density • Heron/egret nest success	The benchmark value for nest density is the average density observed from 1991 to 1995, calculated for each Bay region. For nesting success, the benchmark is the average value observed between 1994 and 1998.
	• Winter waterfowl abundance	The benchmark calculated for the four Bay regions is the mean per species count of dabbling ducks and diving ducks from 1989 to 1993.
ECOLOGICAL PROCESSES		
Flood events	• Frequency and magnitude of high freshwater inflow events	The benchmark consists of the number of years in the past decade in which inflows exceeded 50,000 cfs for a total of 90 days during the year; the average flow during the 90 days of highest flow in the year; and the number of days flows exceeded the 50,000 cfs flood threshold in given year.
Food web	• Number of young reared per great blue heron and great egret successful breeding attempt	The benchmark is the number of young reared per brood observed from 1991 to 1995, calculated across all regions of the Bay (2.17 young per brood).
	• Number of Brandt's cormorant young per breeding pair on Alcatraz Island	The benchmark is the average number of young reared per breeding pair at the Southeast Farallon Islands reference site between 1991 and 2005 (1.69 chicks fledged per pair).
	STEWARDSHIP	
	Individual and community actions	
	• Recycled water use	Benchmarks are previous projections for recycled water use, potential demand for recycled water, and total wastewater available for recycling.
	• Urban water use	The California Department of Water Resources 2020 goal for Bay Area residential consumption is 124 gallons per day per person.
	• Coastal cleanup (volunteer effort)	The volunteer stewardship benchmark is the number of volunteers participating in Coastal Cleanup Day in 1998.
	• Public access (trails completion)	The goal is the completion of the 500-mile regional hiking and bicycling trail around the perimeter of San Francisco and San Pablo Bays. The Bay Area Ridge Trail goal is 550 miles of trail along the ridgelines surrounding San Francisco Bay.
	Management actions (example)	
	• Dredged material disposal and reuse	The goal used was in-Bay disposal reduced to approximately 1.25 million cubic yards per year; annually no more than 20 percent dredged material to be disposed of in-Bay; at least 40 percent to be beneficially reused or disposed of at upland sites; remainder to be disposed in deep ocean site.

DAVE PARKER



must represent the Bay's characteristics broadly by integrating the many detailed scientific measurements that are available about the ecosystem.

In several instances a suite of indicators represents a particular attribute. For example, this report includes measurements for several different indicator species that reflect the health of the Bay's living resources. For simplicity, in some cases multiple indicators were combined into a single index.[8] Readers should recognize that there are important attributes of the Bay for which we do yet have indicators, such as the ecological processes of nutrient cycling and sediment transport, or an indicator to represent the myriad of creatures that live in the Bay sediments. There are also indicators that we would like to report on but for which no data are available, and so the set of indicators in this report will hopefully be expanded in the future (See Next Steps).

STEP 3: Determine benchmarks for evaluating the indicators

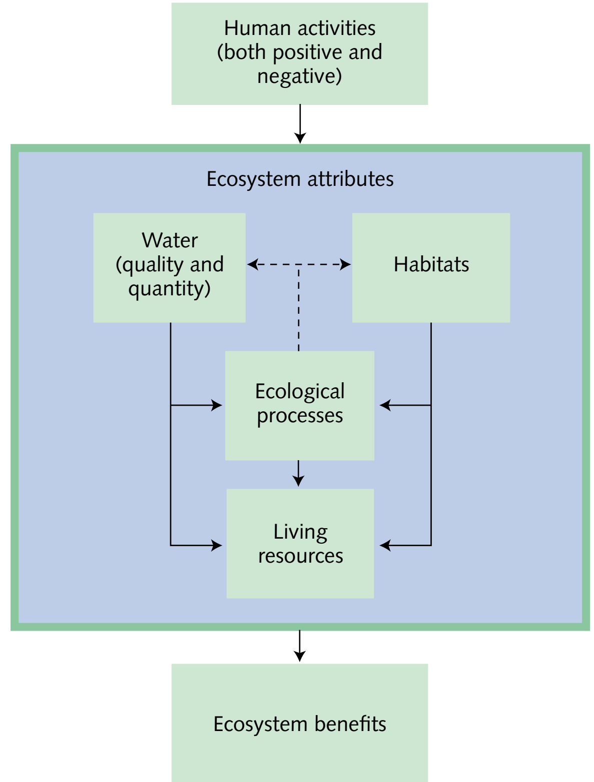
The last step was to determine benchmarks against which to compare the measured values for the indicators. Having benchmarks is essential for evaluating the status of the Bay's attributes. Benchmarks allow us to make definitive statements that can be used to assess how far we've come toward a goal or how far we still have to go.

In some instances, whether through law, regulation, or other public process, quantitative standards or goals have been established that were used as benchmarks; for example, water quality objectives set for specific chemicals, and the goal of restoring 100,000 acres of tidal marsh around the Bay established in the stakeholder-based *Baylands Ecosystem Habitat Goals* report published in 1999.

When such adopted goals were not available, we derived benchmarks using best professional

Figure 1. The attributes of a healthy Bay ecosystem and their relationship with each other and human activities.

The status of these attributes is a product of a dynamic ecosystem. The attributes are constantly being shaped by natural and human influences.



judgment to identify a reference condition against which to compare the measured value of the indicators or indices. For instance, to evaluate the status of some of the fish indicators, we used the average values for 1980–89 as the reference condition.

Selecting reference conditions is further complicated as long term studies document that climatic and ocean conditions influence the Bay on the scale of years to decades. This means changes determined by reference to a previous decade can be caused by ecological changes beyond the influence of Bay Area residents. We present the reference conditions in this report in the spirit of starting an important regional dialogue in which we continue to develop and refine goals and benchmarks for use in future assessments of the Bay's health.

WHERE TO LEARN MORE

This report is a condensed presentation of a large amount of technical information. It is meant to give a snapshot of the Bay's health to those who are interested but who do not have the time to read more detailed technical materials about the various ecological attributes and indicators described in the following sections.

For those who want to read that material, a Technical Appendix to the State of the Bay report is available on-line on the Estuary Partnership website (www.sfestuary.org). There you will find background information about the various indicators, including the rationale for their selection, calculation methods, sources of data, and more details about the results of the analysis.

Readers can find other materials related to the state of the Bay on our website (www.sfestuary.org) and at the San Francisco Estuary Institute's web site (www.sfei.org).

MICHAEL BUKAY

LEN BLUMIN

The South Bay Salt Pond Restoration Project, the largest tidal wetland restoration project on the West Coast, will restore 15,100 acres of industrial salt ponds to a rich mosaic of tidal wetlands and other habitats. Under the leadership of Senator Dianne Feinstein, the South Bay Salt Ponds were purchased in 2003 from Cargill Inc. Funds for the purchase were provided by federal and state resource agencies and several private foundations. The 15,100 acre purchase represents the largest single acquisition in a larger campaign to restore 40,000 acres of lost tidal wetlands to San Francisco Bay.

The salt pond effort is about to move into a new phase. Phase 1 included seven projects.

"We're getting ready to wrap up Phase 1," says project manager John Bourgeois. "After a series of stakeholder meetings to solicit input, we recently decided what the Phase 2 projects are going to be." The project, he explains, is moving carefully to ensure that habitat restoration doesn't conflict with flood control priorities in a part of the Bay that is particularly vulnerable to the effects of rising sea levels.

The restoration area includes the Department of Fish and Game reserve at Eden Landing and the Alviso and Ravenswood sections of the Don Edwards National Wildlife Refuge. Bourgeois also collaborates with the US Army Corps of Engineers, the San Francisco Bay Regional Water Quality Control Board, and local agencies like the Santa Clara Valley Water District and the Alameda County Flood Control District.

"We established bookends of what the project could look like," he explains. One scenario calls for 90 percent of the area to be restored to tidal marsh, with 10 percent remaining as managed ponds. The alternative is a fifty-fifty split. "In Phase 2 we're still trying to get up to 50 percent," Bourgeois adds. "We need results from the adaptive management program to refine that decision. We're not moving past fifty-fifty until we have the science to allow us to. Some want us to move really fast and some think we're moving too fast."

Adaptive management involves, among other things, coping with the 45,000 California gulls that nest on islands and levees among the ponds. Last December pond A6, one of the Alviso ponds, was breached, flooding a former gull nesting colony. The concern is that displaced gulls will add to the predation pressure on shorebirds like American avocets, black-necked stilts, and endangered western snowy plovers. "We banded about a thousand gulls there," says Bourgeois. "Some are going to other existing colonies at Mowry and Newark." "It's the best-case scenario," says Cheryl Strong of the US Fish and Wildlife Service. "They didn't colonize new areas." "We're targeting areas like SF2, A22, and Eden Landing where we don't want them to show up," Bourgeois adds.

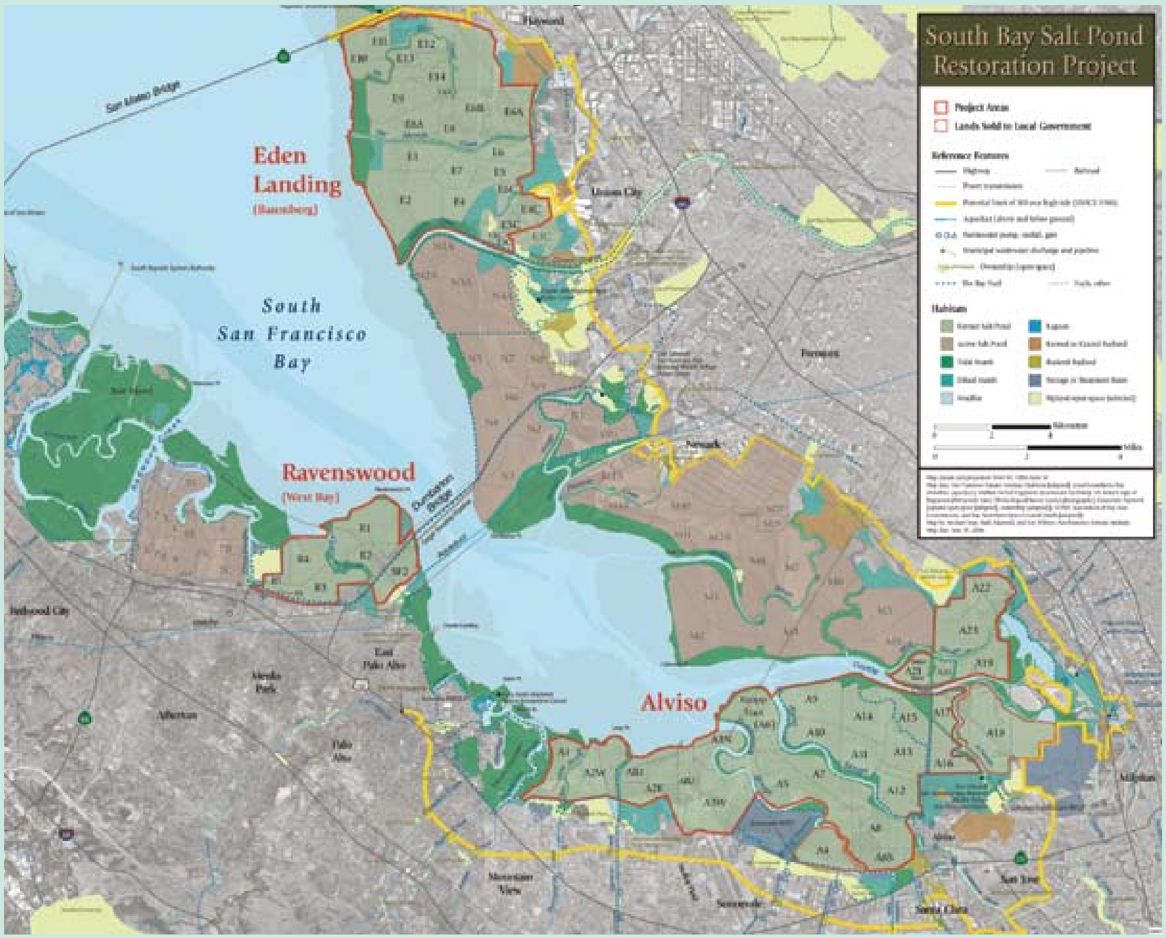
Other issues being addressed through adaptive management include methylmercury generation and dissolved oxygen levels in the ponds. "We're working closely with the Water Board on mercury," Bourgeois notes. Pond A8, which was opened to the tides in June, will be a key test site. "As for dissolved oxygen, we've tried to maximize the amount of turnover we get in these ponds, also working with baffles and aeration. The problem is a lot better. The US Geological Survey is studying larger and deeper ponds like A3W, where getting enough water turnover in all the little nooks and crannies is difficult."

Ravenswood pond SF2 near the west end of the Dumbarton Bridge is an ongoing experiment in habitat enhancement: "The ponds were engineered to make salt, not as wildlife habitat. We wanted to take a smaller footprint and modify it specifically for wildlife species, trying to create as much nesting and foraging habitat for shorebirds as we can. Based on similar work in the Central Valley, we built 30 islands in two different shapes, half round and half linear. The whole back third of the pond is dry seasonal salt panne for the plovers. Volunteers have spread oyster shells to create camouflage for plover nest sites, and we built moats to exclude mammalian predators."

Project staff thought it would take a couple of years for the birds to discover SF2. Bourgeois says, "We had hundreds of waterbirds within two or three weeks of opening it up. This spring we had a pair of snowy plovers nesting on each of four islands." A hundred pairs of American avocets and a few pairs of black-necked stilts also nested. Strong says the pond, with areas of varying depth, attracted large numbers of both dabbling ducks (shoveler and pintail) and diving ducks (scaup, common goldeneye, and ruddy duck) during its first winter; the ducks forage by day and use the islands as night roosts. Migratory shorebirds, including least sandpipers, marbled godwits, willets, and semipalmated plovers, foraged along its edges. Biologists will continue to monitor shorebird and waterbird use to inform pond management and future managed pond projects.

Proposed Phase 2 steps at the Ravenswood unit will include tidal restoration of Pond R4 and enhanced management of R5 and S5 as bird habitat. The project is also looking at restoring Alviso ponds A1 and A2W, next to Mountain View's Shoreline Park, to tidal marsh. The "Island Ponds," A19, A20, and A21, breached for tidal circulation in 2006, will be enhanced. "We're considering additional breaches of the Island Ponds along Mud Slough on the north side. The Corps of Engineers is also analyzing the Alviso complex, one of their top priorities, for their Shoreline Study. Flood protection is one of our three major goals, along with restoration and public access. We aren't taking any actions in Phase 1 or Phase 2 at Alviso that would increase flood risk."

South Bay Salt Pond Restoration Project



Flood control imperatives will also drive Phase 2 at Eden Landing. "The whole southern half between Alameda Creek and the Flood Control Channel will go to tidal restoration," says Bourgeois. "But we can't restore that area without flood protection for Union City. We're working closely with the Alameda County Flood Control District on that." He also points out that the spine of the Bay Trail will go through Eden Landing. Balancing the three goals here will require a "multi-year and multi-stage" process.

Looking back at Phase 1, Bourgeois says the biggest and best surprise is the rapid rate of sedimentation in restored ponds: "The rate has been much faster than projected, with lots of marsh development. The South Bay is very sediment-rich. In light of sea level rise projections, we find we need to capitalize on that as soon as we can."

For the future, he sees "a lot of uncertainties. Flood protection is one of our biggest challenges. Pretty soon we'll hit a point where we can't do any more restoration until we have real flood protection in place." Bourgeois says project managers are working with the Corps and local flood control agencies to make sure these elements come together. He is also looking forward to seeing more results from the project's monitoring program in the coming years to better understand how the system is responding to these large-scale changes. To see more maps of the salt pond restoration projects, go to www.southbay-restoration.org/maps.

A slightly different version of this article first appeared in ESTUARY NEWS, August 2011.