# Troubling Waters

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# Troubling Waters

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**One of the world's richest deltas has been radically replumbed, its ecosystem is collapsing, and Californians are realizing their water supply is tapped out. Despite decades of efforts—and some positive trends—solutions may not be any closer. Downstream, the San Francisco Bay looks good by comparison.**

The largest estuary on the western coasts of the Americas carves dominant features on the face of California. The San Francisco Bay and, especially, the Sacramento–San Joaquin Delta also figure prominently in lives and livelihoods throughout the state, the world's seventh largest economy.

Although San Francisco Bay is well known to the nation and world, even many Californians ignore the delta as an uninteresting "flyover" region, not realizing how much they depend on it. Possibly the largest plumbing project in the world centers here, and "heart" metaphors are apt, as in, If water is the lifeblood of California, the delta is its heart. But surprisingly few people realize that this heart is failing.

"This is a critical system which is telling us a lot of things right now," says Tina Swanson, a biologist and head of the Bay Institute, in Novato. Increasingly, headlines blare the messages: Crashing fish populations. Vulnerable levees. Judicial rulings ordering reduced water exports to protect endangered species. Record drought. Water rationing. Farming failures. And an upsurge in panels, processes, task forces, and reports, which seems ominous yet is potentially hopeful.

The good news is that experts as well as stakeholders agree that the delta is in crisis and deteriorating. Unfortunately, it remains politically deadlocked, and the complexity of the problems precludes simple solutions.

## Lessened by legacy

California's delta fans out at the confluence of the two great rivers that drain the Central Valley, the southwest-flowing Sacramento River, which brings most of the water, and the northwest-flowing San Joaquin River. Unlike most deltas, it broadens *upstream* from where the water squeezes through mountains on its way to the bay.

Originally, land and water ecosystems interconnected in a rich, labyrinthine marshland covering more than 2500 square kilometers ($km^2$). "This was one of the richest ecosystems on the planet in terms of its ability to fix carbon," says geologist Jeffrey Mount, director of the Center for Watershed Sciences at the University of California, Davis. In California's mediterranean climate, most precipitation falls during three winter months, as rain in the valley and snow in the Sierra Nevada. A winter freshwater pulse was followed by snowmelt runoff—timed-release water—that peaked in spring and dwindled over summer. Tides also influence the delta, and during the driest part of the driest years, brackish water made its way farther inland. "Native fishes evolved in a system that fluctuated," says Peter Moyle, a fish ecologist at the University of California, Davis.

Then came the gold rush, followed by statehood in 1850. Hydraulic mining in the Sierras literally washed away mountainsides, sending tons of sediments downstream, raising some streambeds as much as six meters. Settlers converted rich delta peat to farms by diking, draining, and channeling. By the 1930s, the delta was divided into about 60 "islands" surrounded by 1700 km of levees. The bay, too, lost more than 85 percent of its protective, productive fringe of tidal marsh to farming, fill, and salt ponds. That trend is now being reversed.

Water conflicts and plans for transfer and storage projects grew with the population. The federal Central Valley Project, the largest in the state, was built in the 1940s and 1950s, mostly to serve agriculture. The State Water Project, built in the 1960s, was intended to meet growing urban as well as agricultural needs. Both include big dams and elaborate conveyance systems. Large municipalities also constructed their own water projects, and most rivers in the state are dammed. Now, delta water flows—over mountains—as far as San Diego, 800 km south, and two-thirds of the population (more than 23 million people) depend on the delta for at least some water.

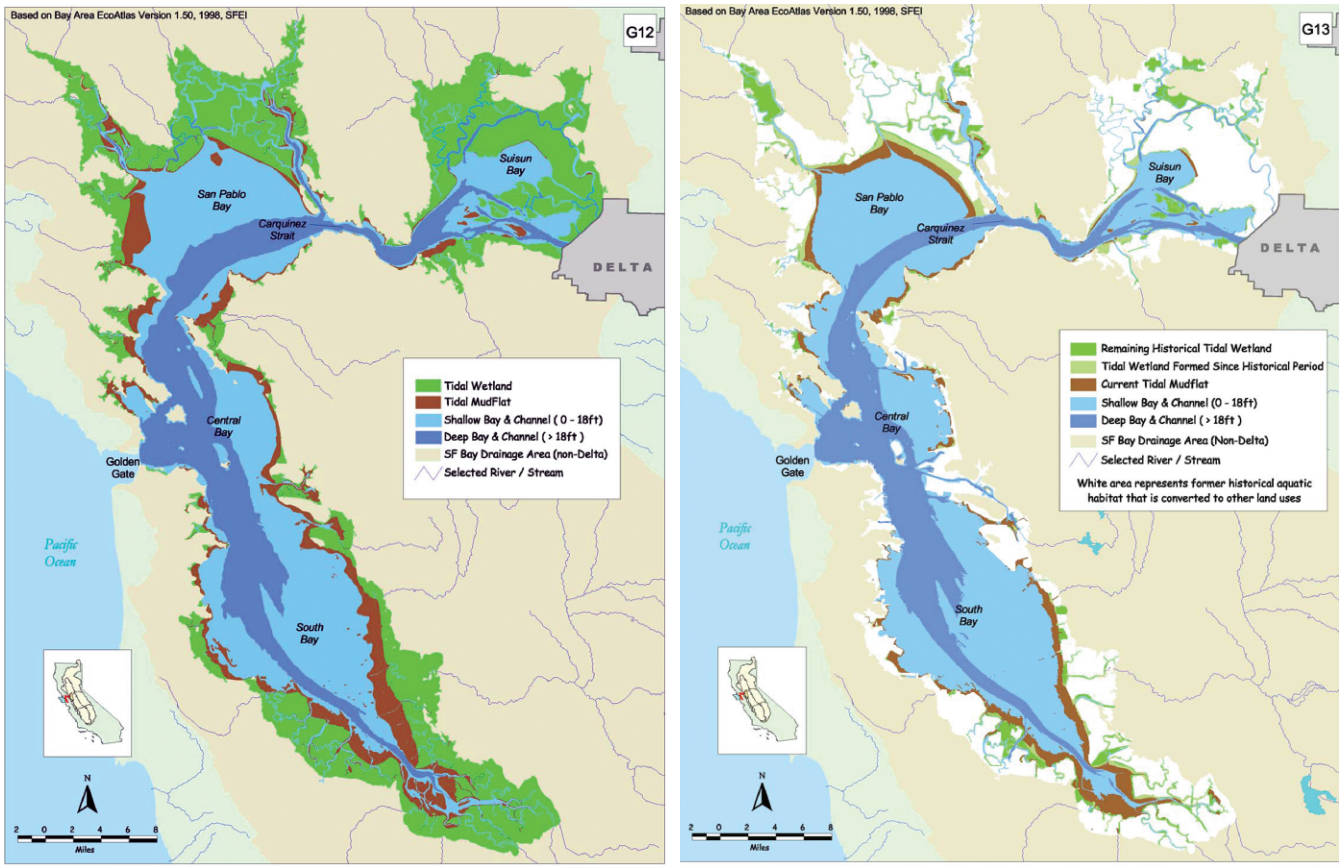
*This satellite map of the San Francisco Estuary shows the delta fanning out upstream (upper right). Water flows into Suisun Bay, then winds through the Carquinez Strait to San Pablo Bay and the Central Bay, before flowing out through the Golden Gate. Colorful salt evaporation ponds ring the South Bay. Gray shows the urban buildup of some seven million people. Landsat Thematic Mapper satellite image superimposed on digital elevation models: Robert E. Crippen (NASA Jet Propulsion Laboratory) and Ross Stein (US Geological Survey).*

The delta receives runoff from about 40 percent of California's land area and about half of California's total stream flow. But just under half the water that would historically have flowed through the Golden Gate actually makes it out to sea. Nearly a third of the water is now diverted before even reaching the delta, and most years about 100 km of the San Joaquin River runs dry. About 80 percent of the diverted water irrigates hundreds of thousands of hectares in the San Joaquin Valley, supporting California's $32 billion agriculture industry.

To slake the thirst of farms and growing cities, dams retain water that would have flowed in spring and release it instead in summer and fall, destroying the dynamic pattern of runoff pulses. "Over the past 25 to 30 years we've increasingly tried to stabilize the delta and make it into a freshwater system," Moyle says. Collapsing populations of fish, bellwethers in the system, provide ominous feedback.

## Fish tales

California's salmon fishery ranks second only to Alaska's. But in the spring of 2008, for the first time, federal officials shut down the West Coast's ocean salmon

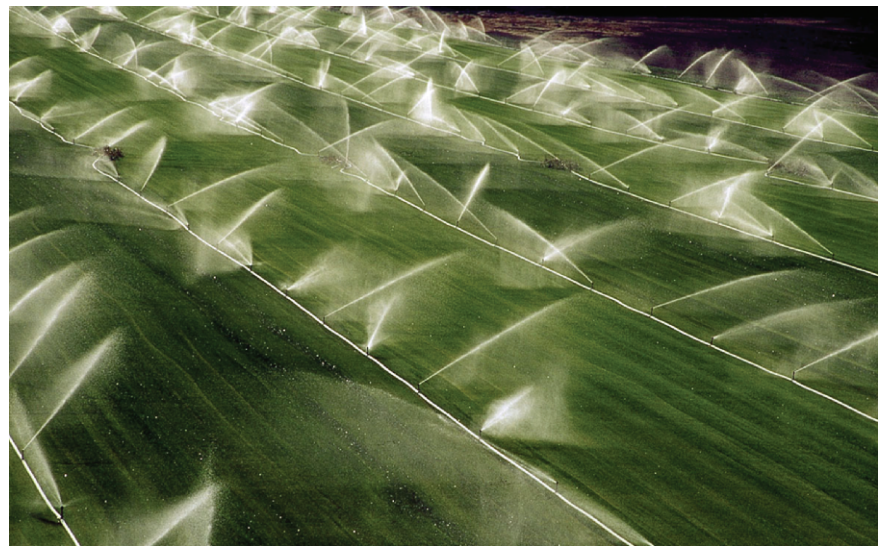



**San Francisco Bay historical aquatic ecosystem** | **San Francisco Bay current aquatic ecosystem**

*The Sacramento–San Joaquin Delta was once an immense tidally influenced freshwater wetland. These maps show the dramatic reduction in aquatic habitats between the mid-1800s (left) and 1997 (right). Former natural habitat converted to other uses through diking and channelization is shown in white. Maps: The Bay Institute.*

season after a dramatic drop in the number of fall-run chinook returning to the Sacramento River to spawn. The cause of the crash—to less than half the minimum set by regulators—is unknown. Other salmon runs are also depressed, including coastal coho that do not navigate the delta, which implicates ocean conditions. The chinook probably endure an assortment of assaults. Two other endangered runs of chinook pass through the delta, in the winter and spring, and Moyle credits upstream creek restoration projects with helping these runs survive. "We know a lot about how to fix stream habitats for salmon. Then they get into the delta. You've got to fix all the pieces," he says.

"Closing the fishery cannot be the only management response we make," Swanson says. "The whole point of managing salmon is to have a fishery." In July 2008 a federal judge agreed, ruling that state and federal water-project operations must



*Most of California's diverted water goes to agriculture, which could use much less water and still be economically sound, experts say. Farmers are increasingly water-use efficient, but change needs to happen even faster. Recommendations include new rate structures for water, stiffer regulations, rebates for efficient irrigation systems, and reduced farm subsidies for low-value crops that use a lot of water. Photograph: California Department of Water Resources.*

be modified to protect endangered chinook salmon and steelhead populations.

Returning salmon are usually two to three years old, so overlapping cohorts buffer against a few bad years. The threatened delta smelt, however, which live one year, could wink out quickly. Once the most abundant fish in the delta, and found only here, the silvery finger-length smelt spend most of the year in schools eating zooplankton along the brackish edge of the freshwater–saltwater mixing zone. In winter they migrate upstream, disperse into smaller channels, spawn, and die. Unfortunately, their 38-km range overlaps an area where huge pumps divert water.

Despite fish screens and "salvage" procedures, the pumps still confuse and kill fish, and in 2007 a federal judge imposed restrictions on water exports to protect the beleaguered smelt. Before that ruling, the state and federal projects were exporting a record amount of water, and the fish count dropped to less than 3 percent of what it had been when delta smelt were listed in 1993. But the pumps are only part of the problem.

"The majority of the aquatic species that inhabit the delta are not native," Moyle says. In fact, it's possibly the world's most invaded estuary, with an increasing rate of introductions. Just two examples show how invaders rob native species of food and shelter. Brazilian waterweed has taken over large parts of the delta in recent decades. Growing within channels, it slows the current and encourages sediment settling. Delta smelt and other fish that prefer some turbidity now have fewer places to hide from predators. Meanwhile, in more brackish water, the filter-feeding Asian overbite clam has become so abundant that it clears the water column of plankton, stripping the bottom out of the food web.

Delta denizens also face episodic toxic pollution ranging from agricultural runoff and overspray of fertilizers and biocides to excess ammonia from sewage. Wim Kimmerer's lab at San Francisco State University's marine laboratory had to change procedures for growing zooplankton when, after exchanging culture water with water taken from the delta, all the animals died. "You have to wonder—

## Bay Watch

The lower estuary, San Francisco Bay, is in fairly good shape relative to the delta. One saving grace may be that the bay is influenced more by the ocean than by freshwater flows from the delta, where human control has radically altered the hydrology. "The further upstream you go, the worse it gets," says Tina Swanson, head of the Bay Institute, which assesses the estuary by monitoring a number of indicators and keeping an ecological scorecard.

However, because of water supply issues, research funding seems to vary inversely with salinity. More is known about the delta and North Bay; the Central and South bays are relatively neglected. "It's shocking how little we know about what's living out in the bay," says Andrew Cohen of the San Francisco Estuary Institute, in Oakland.

San Francisco Bay is not prone to eutrophication or nuisance algal blooms, and the Clean Water Act made a big difference here, but pollutants persist. Fish are mostly native, but state officials advise adults to limit their sport fish consumption to at most two meals per month, because of PCBs (polychlorinated biphenyls), mercury, and a variety of biocides. Mercury occurs naturally in the Pacific Coast Ranges around the bay, and gold miners used quicksilver in the Sierras, so mercury lingers throughout the watershed.

Concern persists among some of the seven million people who live here. Urbanization was shrinking the bay until the 1960s and 1970s, when public outcry halted rampant filling. In 2007, when a cargo ship spilled more than 50,000 gallons of oily bunker fuel in the Central Bay, officials couldn't use all the volunteers who came out to help clean beaches and birds. Lawmakers responded with about a dozen bills reforming every aspect of preventing and cleaning up oil spills.

Stanching the flow of exotic species is a current worry. "There's still not a mature structure around it the way there is around these other issues," Cohen says. Initial focus has centered on ballast-water tanks, which help stabilize ships. Filling tanks in one port and discharging in another has spread aquatic creatures around the globe. California began requiring midocean ballast water exchange in 2000. Washington and Oregon quickly followed, as did the federal government several years later.

"Ballast-water exchange is the law, but we have no idea whether it's working, really, because there's no monitoring," Cohen says. Next steps are to set standards for how many living organisms can be released, and to rein in other sources of exotic organisms, such as bait and aquaculture. Relative to the system for regulating, monitoring, and watch-dogging chemical pollutants, societal control of biological pollutants is still in its infancy, Cohen says.

*The bellwether delta smelt (*Hypomesus transpacificus*) is just two to three inches long and smells like cucumbers. Once the most abundant fish in the estuary, it was listed as threatened in 1993 and is now so scarce that it could die out in the next few years. Photograph: B. Moose Peterson, US Fish and Wildlife Service.*

what kind of place is this?" Kimmerer asks.

Three other delta fish populations also nosedived earlier this decade, and alarmed scientists dubbed the crash "pelagic organism decline," or POD. POD remains mysterious, but seems to further indict ecosystem conditions. "It's gotten to be a fairly hostile environment," Moyle says.

## Certain uncertainties

In some cases, the water is too warm for fish, a trend likely to worsen with climate change. The prediction for California: warmer and drier. With more precipitation falling as rain instead of snow, winter's runoff pulse will increase, so both floods and droughts become more likely. Factor in sea-level rise and the two-in-three chance of a significant earthquake within the next several years, plus experience with Hurricane Katrina, and those old delta levees come to mind—or should.

Most of the delta has subsided five meters or more below sea level because of the conversion to farming: as peat soil dries, microbial oxidation turns the carbon in it into gas. For 100 years, farmers kept building ever-bigger levees to hold out channel water. "It evolved into a network of 1100 miles [1700 km] of levees that protect holes in the ground," Mount says.

In one doomsday scenario—a strong temblor close to the delta causing levees to collapses like a row of dominoes—the delta becomes an open estuary as large as Lake Tahoe, roughly doubling the size of San Francisco Bay. Such a disaster would be felt around the state because, besides being home to a half million people, the delta is crisscrossed by highways, railroads, high-voltage lines, and gas lines. And, of course, there's the already vulnerable water supply.

A more likely scenario is that several western delta islands will fail. They're closer to fault zones, deeply subsided, and have some of the worst levees. Sooner or later, a lot of the delta is probably going to be under water; the newly created aquatic habitat might be good for desirable fish, although nobody knows. The trouble is, when subsided islands fill, they draw salt water inland.

## Restoring Wetlands: Marshing Back to the Future

Curious air passengers often remarked on the colorful patchwork of huge ponds ringing south San Francisco Bay, especially when blues, greens, and browns gave way to striking shades of maroon and even orange. In 2003, all that began changing for the better with a landscape-scale wetland restoration—the largest on the West Coast and one of the largest in the nation—that's reversing a 150-year-old trend.

Diking for salt production obliterated tidal marsh in the South Bay. Solar evaporation ponds concentrate salt from bay water through a series of increasingly salty ponds over several years. Pond colors come from various organisms that prefer differing salinities. But salt making has stopped, and managers are using the bay's own tidal flushing to fill the ponds with sediment and resurrect the marshes that the endangered California clapper rail and salt marsh harvest mouse need to survive.

"Ironically, the thing that wiped out the tidal marsh turned out to be what saved this opportunity for us, decades later," says Steven Ritchie, executive project manager for the South Bay Salt Pond Restoration Project. "We would have built something out there." Instead, a restoration roughly the size of Manhattan Island is now collaboratively managed by the California State Coastal Conservancy, the US Fish and Wildlife Service, and the California Department of Fish and Game.

"We should think about how large that 15,000 acres [6000 hectares] is in the context of the South Bay, and it's huge," says Denise Reed, of the Laboratory for Coastal Restoration Science at the University of New Orleans, who served on the national science advisory panel for the project. "The consequences of that restoration will be felt outside the boundaries of the ponds." Other restoration projects around the bay add a roughly equal area.

Situated along the Pacific Flyway, San Francisco Bay is one of the most important places in North America for migratory birds, which need it for a critical refueling stop as well as an over-wintering site. As urbanization destroyed their former habitats, some shorebirds and waterfowl shifted to using salt ponds. Now, as managers restore tidal action and marsh, they want to avoid damaging bird populations that currently depend on the ponds.

Although much is known about the bay, not enough is known to predict how wildlife will respond to various restoration efforts. For example, an unexpected explosion in the California gull population, and the gulls' devastating predation on chicks in a nearby avocet colony, show that restoration is not so simple as reestablishing natural processes and letting nature take its course. Tough questions arise. "How closely do you manage for specific species?" Ritchie asks.

Because of the large number of such uncertainties, the restoration will progress in phases over 50 years and be guided by adaptive management. In this approach, up-front and ongoing cycles of monitoring, evaluation, experimentation, and adjustments allow science to inform management decisions in modifying the landscape over time.

"We haven't done that in the past," Reed says. Instead, pursuing specific outcomes and narrow goals caused inadvertent damage. "That's where we are in the Sacramento–San Joaquin Delta, and in the Everglades, and in coastal Louisiana—unintended consequences," she says.

In adaptive management, interventions are experiments designed to reveal something new about the system, and here, pairs of ponds can act as controls for each other. Managers are initially aiming for a mix of half tidal marsh and half pond habitats managed for birds. "We think that provides enough tidal marsh acreage to help the two endangered species achieve recovery," Ritchie says. Managers would prefer to reach as much as 90 percent tidal marsh and just 10 percent as managed ponds, but they will have to wait and see how the ecosystem responds.

Ritchie emphasizes that the area will never be like it was originally. But with humility as one of the most important restoration values, the early investment in good science is expected to pay dividends for generations.

The delta's looming predicaments have prompted more rounds of high-level panels and reports. Talk has returned to a peripheral canal, which, like a coronary bypass, moves precious liquid around a trouble spot. "The water in the delta is not that good anyway," Mount says. "You're looking at a progressive decline in one of the richest farming regions in the world because you're pulling salt water out of this delta." The idea is simple in theory: instead of running good, clean Sacramento River water through the delta to water project pumps, build an "isolated conveyance" around the delta.

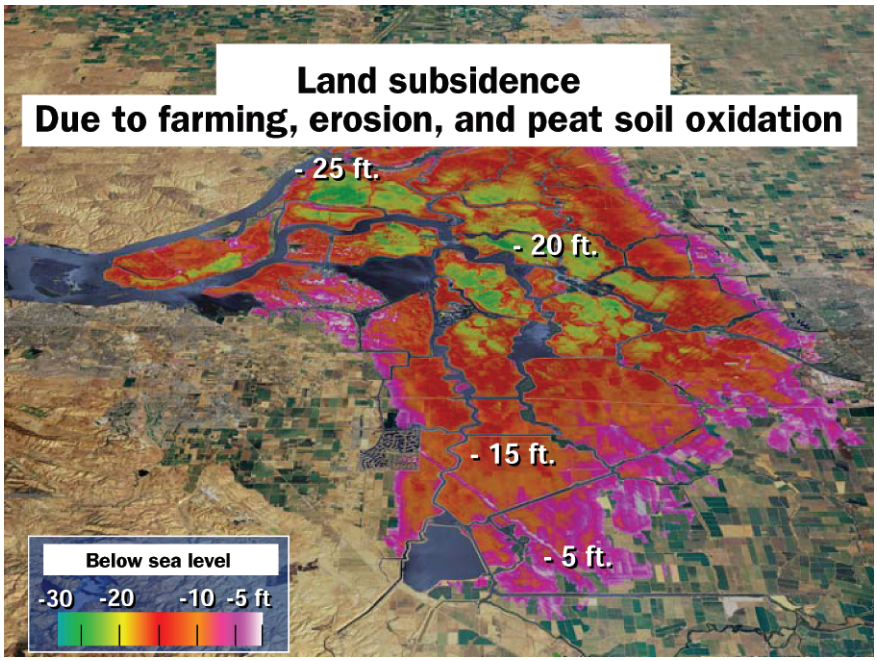
Reality is more complicated, however, both politically and ecologically. California voters roundly defeated a peripheral canal proposal after a heated campaign in 1982. And although such a canal potentially offers benefits for the ecosystem, no one really knows. Some scientists worry that, depending on how such a canal is operated, it might just relocate the problems. Plus, water diversions aren't the only stressor; other ecosystem assaults have to be countered, too.

Even as the delta has dwindled, knowledge and science have evolved, thanks to long-standing state and federal monitoring programs, and multiagency, multistakeholder research efforts. "This is probably one of the best-monitored systems in the world," Swanson says.

Policymakers are paying attention, too. "For the first time in history, all levels of government are grasping the complexity and magnitude of the problem," Mount says. Less than a century ago, people lamented that water flowing out through the Golden Gate was "wasted." Now the Governor's Delta Vision Blue Ribbon Task Force has set the delta ecosystem and a reliable water supply as "co-equal goals for sustainable management of the Delta."

Despite apparent agreement on the need to balance societal demands and ecosystem needs, exactly how to move forward remains unclear. "The Sacramento–San Joaquin Delta is really difficult," says Denise Reed, of the University of New Orleans, who studies restoration projects across the country. Science alone can't solve these multidimensional problems, but scientists must be involved to help work out technically feasible solutions—and determine potential consequences. "The worst thing in these difficult situations is if you get people saying, 'We want to manage for *x* and *y* and *z*,' but really it's impossible," Reed says.

River deltas are inherently dynamic, but California's resilient delta is gone, altered so radically that there's no way to restore it to historical conditions. More than a century of efforts to "stabilize" the delta have instead produced only a brittle, increasingly precarious interim construct. California's water heart is bound to change. Just how catastrophic that adjustment will be depends on whether society and governance respond appropriately and in time.




*Once a vast marsh floodplain of rich soil and labyrinthine channels, by the 1930s the San Francisco Delta was converted to about 60 "islands" that have subsided behind increasingly vulnerable levees. When the peat soils were drained, dried, and exposed for farming, they became susceptible to microbial oxidation, which is responsible for about 75 percent of the loss. Graphic: California Department of Water Resources.*

For more information, visit these sites:

*www.science.calwater.ca.gov/publications/sbds.html*
*www.ppic.org/main/publication.asp?i=810*
*http://deltavision.ca.gov/DeltaVisionNewsRoom.shtml*
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