RMP

REGIONAL MONITORING PROGRAM
FOR WATER QUALITY IN SAN FRANCISCO BAY

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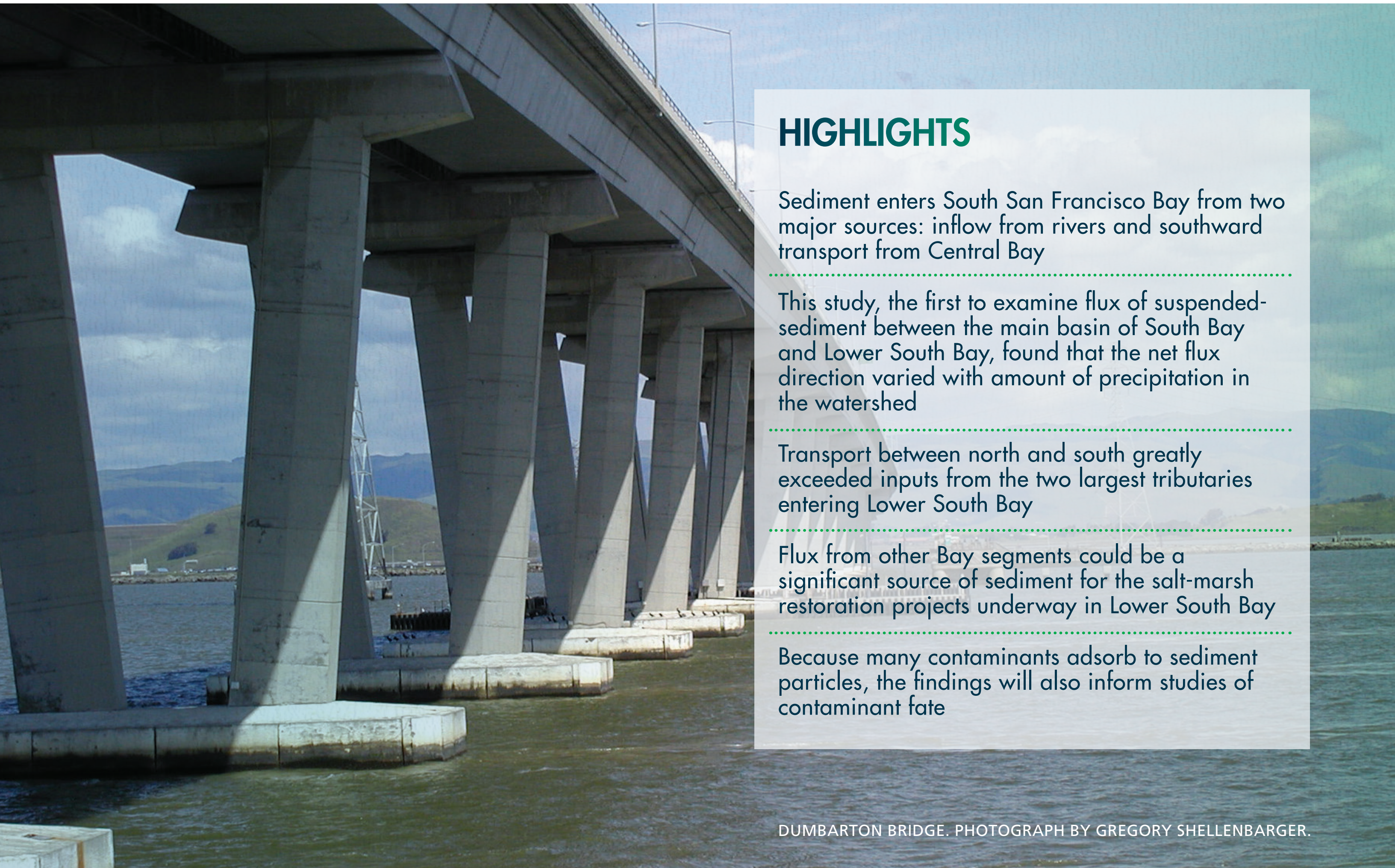
# SEDIMENT FLUX to and from LOWER SOUTH SAN FRANCISCO BAY



## HIGHLIGHTS

- Sediment enters South San Francisco Bay from two major sources: inflow from rivers and southward transport from Central Bay
- This study, the first to examine flux of suspended-sediment between the main basin of South Bay and Lower South Bay, found that the net flux direction varied with amount of precipitation in the watershed
- Transport between north and south greatly exceeded inputs from the two largest tributaries entering Lower South Bay
- Flux from other Bay segments could be a significant source of sediment for the salt-marsh restoration projects underway in Lower South Bay
- Because many contaminants adsorb to sediment particles, the findings will also inform studies of contaminant fate

DUMBARTON BRIDGE. PHOTOGRAPH BY GREGORY SHELLENBARGER.

## WHAT'S INSIDE

## A TURBID ESTUARY

It takes just one look at San Francisco Bay to see that its waters are laden with particles suspended in the water column. Bay waters are usually turbid shades of dark blue, gray, brown, and gold rather than the pale swimming-pool blue of clear waters. This turbidity is caused by river runoff and by resuspension of fine bottom sediment from the shallow waters within the Bay by waves and tides. The northern stretches of the Bay receive large amounts of suspended sediment in river flow from the vast Central Valley watershed. The situation is different in the South Bay (**FIGURE 1**), which has a comparatively small watershed, bringing little river flow or direct runoff into its waters. Water flows from the South Bay watersheds are almost negligible during California's summer dry season, when natural inflows are so limited that municipal wastewater discharges account for most of the freshwater input. To really understand the sources and pathways of suspended-sediment in the South Bay, it is necessary to look not just at inputs from rivers but also at fluxes – inputs and outputs – from the rest of the Bay.

The U.S. Geological Survey (USGS), in conjunction with the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP), has studied suspended-sediment in the Bay since 1993. Since 2003, scientists have monitored suspended-sediment inputs to the South Bay from two main tributaries, the Guadalupe River and Coyote Creek. This fact sheet reports on the first USGS measurements of in-Bay fluxes at the Dumbarton Bridge, the southernmost of the bridges across the Bay. The bridge links Dumbarton Point in Fremont to Ravenswood Point in East Palo Alto and is considered the boundary between the major basin of South Bay and the smaller basin known as Lower South Bay (**FIGURE 1**).

The suspended-sediment that makes the Bay turbid is important for many reasons. High turbidity limits sunlight penetration, which in turn limits algal growth. Some fish in San Francisco Bay, such as the endangered Delta smelt, prefer turbid waters. Others, such as the Pacific herring, may be harmed by excessive turbidity, which can hinder egg hatching success and larval development. The amount of sediment settling from the water to channel bottoms within ports and waterways determines how frequently those areas must be dredged. Conversely, sediment within the Bay has become a commodity, as large volumes of sediment are needed for wetland restoration projects. Many pollutants, particularly organic compounds such as pesticides and polychlorinated biphenyls (PCBs) and some metals such as mercury, adsorb to sediment particles, and sediment transport is a major agent for contaminant movement in the Bay. These last two issues – the need for sediment in habitat-restoration projects and the relations between pollutants and sediment – have fueled increasing interest in suspended-sediment inputs to South Bay.

## SEDIMENT AND THE SOUTH BAY RESTORATION PROJECT

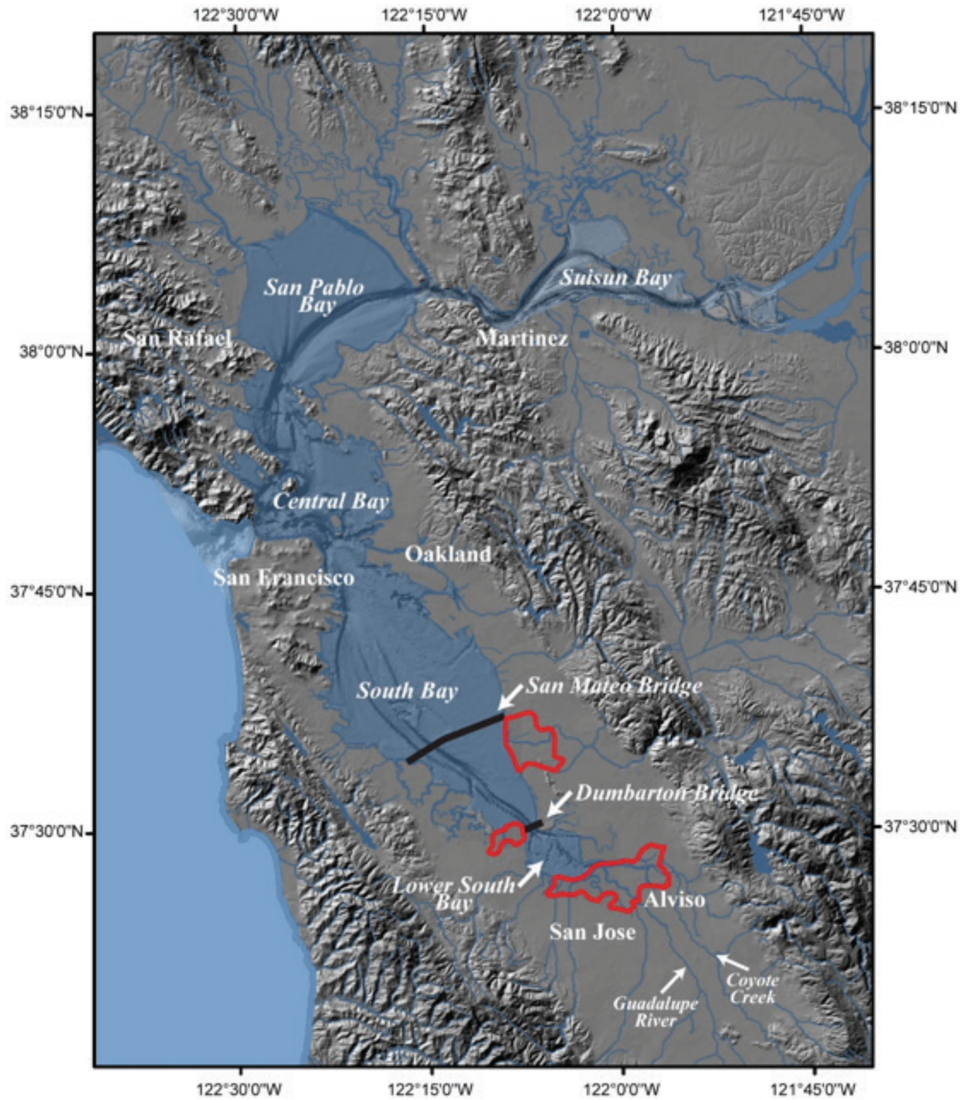
Since the 1850s, San Francisco Bay has lost more than 85% of its tidal marshes, important losses of habitat for endangered species and migrating waterfowl, nursery areas for fishes, and protection against storm surges and sea-level rise. Restoration of tidal marshes fringing San Francisco Bay has become a priority, and the biggest tidal wetland restoration project on the West Coast is currently underway in the main basin of South Bay and in Lower South Bay. In 2003, California, the federal government, and several private foundations purchased more than 15,000 acres of former commercial salt evaporation ponds, part of a 26,000-acre complex that surrounded much of the Bay south of the San Mateo Bridge. Diking off ponds for salt production in the Bay dated from the 1850s, and the brilliant greens and reds caused by the salt-tolerant flora and fauna in the ponds have long astonished visitors arriving to the Bay Area by air. The South Bay Salt Pond Restoration Project (www.southbayrestoration.org) is now breaching some of the salt-pond levees and working to create a mix of tidal marshes and managed ponds.

The need for sediment in habitat-restoration projects and the relations between pollutants and sediment have fueled increasing interest in suspended-sediment inputs to South Bay

An adequate sediment supply is essential to successful restoration of the ponds. Salt marsh vegetation can only take root when water depths are optimal, and in many of the salt ponds, the bottom is too deep. The hope is that Bay waters flooding the ponds will deposit sufficient sediment to raise the pond bottom elevations to allow salt marsh plants to begin colonization.

The problem of deep pond bottoms was caused by subsidence, a process in which an excess of groundwater was pumped from the aquifer, and the overlying soils compacted, settled, and sank. Subsidence is a particular problem near the once-bustling port of Alviso, located at the southern end of Lower South Bay in an area with many salt ponds included in the restoration effort (**FIGURE 2**).

Planners for the Restoration Project estimated that it would take 29-45 million cubic meters (38-59 million cubic yards) of sediment to bring the ponds slated for restoration up to needed elevations, about 18-28 million metric tons (20-31 million tons) of material. Those estimates did not account for sea-level rise, so the needs may be even greater. The sediment deficit is viewed as one of the greatest challenges to habitat restoration in the Bay, one that could take many decades to overcome.

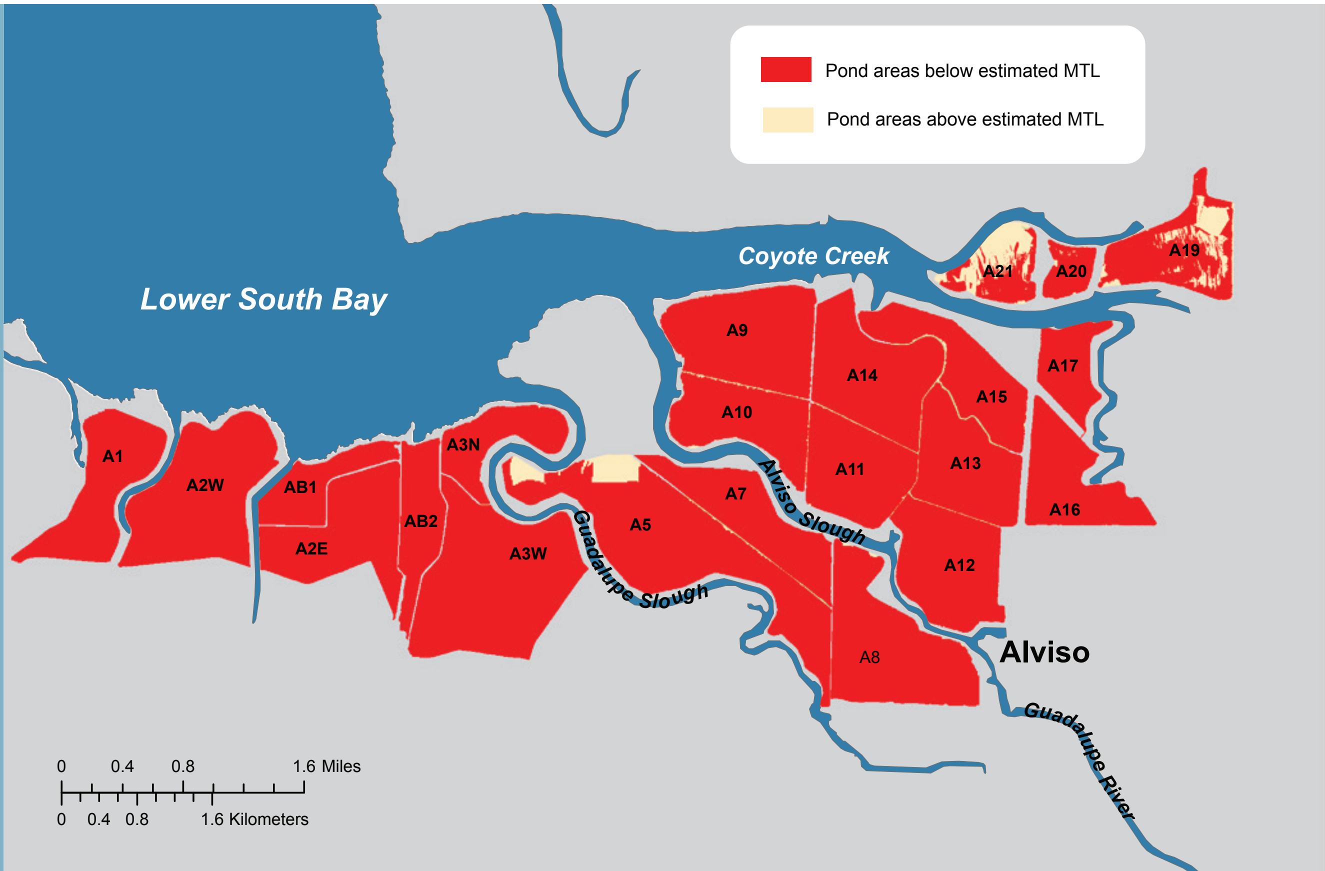



## Figure 1.

**San Francisco Bay and the surrounding area.** Lower South Bay is the primary study area, with Coyote Creek and the Guadalupe River as the main tributaries. The regions marked in red are former commercial salt evaporation ponds that are part of the South Bay Salt Pond Restoration Project. The Coyote Creek watershed is 205,000 acres, and the Guadalupe River watershed is 109,000 acres.

## Figure 2.

**At the southern end of San Francisco Bay, near Alviso, salt evaporation ponds have subsided to depths below the mean tide level (MTL), the approximate depth at which salt marsh plants begin to colonize.** Red areas are restoration pond areas that have subsided below the mean tide level, yellow areas are still above mean tide level, and grey areas are unsurveyed. The ponds are numbered following the Restoration Project's system of identification.

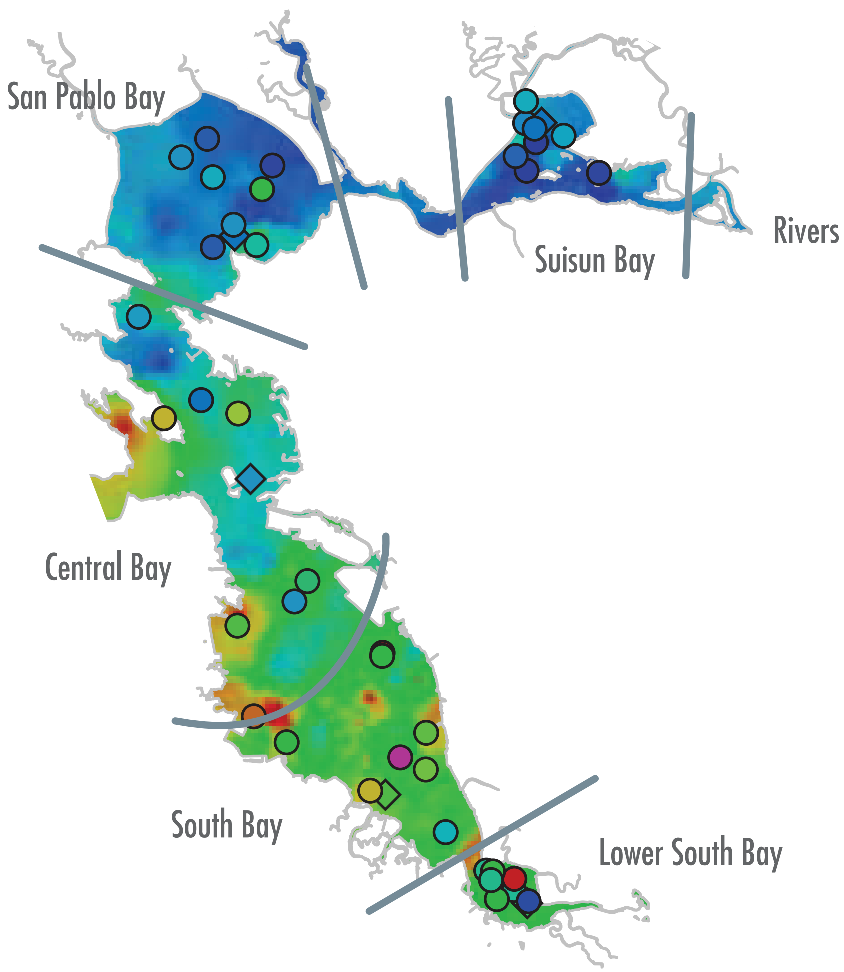


# SEDIMENT CONTAMINANTS

Annual monitoring by the RMP has shown that the southern regions of San Francisco Bay have some of the most contaminated surface sediment (**FIGURE 3**). Lower South Bay is especially at risk for contaminated sediment, as one of its major tributaries the Guadalupe River was impacted by the historic New Almaden Quicksilver Mining District, which was once the largest producing mercury mining area in North America. The Guadalupe River is also heavily contaminated with PCBs, a legacy of industrial activity from the 1950s through the 1970s.

Concentrations of one toxic form of mercury, methylmercury, have been consistently high in South Bay and Lower South Bay sediment: about 0.70 parts per billion (ppb) compared to a Bay-wide average of 0.30 ppb. High methylmercury levels are considered one of the greatest threats to South Bay wildlife and to people who regularly eat fish from the Bay.

PCBs and other contaminants also occur in relatively high concentrations in South Bay and Lower South Bay sediment samples. The contaminants are of concern because of the effects they can have on the fish and wildlife inhabiting South Bay waters. The concerns also complicate the prognosis for successful wetland restoration. The Restoration Project is assessing how actions may improve or worsen conditions by, for example, burying contaminated sediment under new, cleaner layers of material, attracting new populations of birds or other wildlife that could be exposed to contaminated sediment, or creating conditions that promote conversion of contaminants to more toxic forms.

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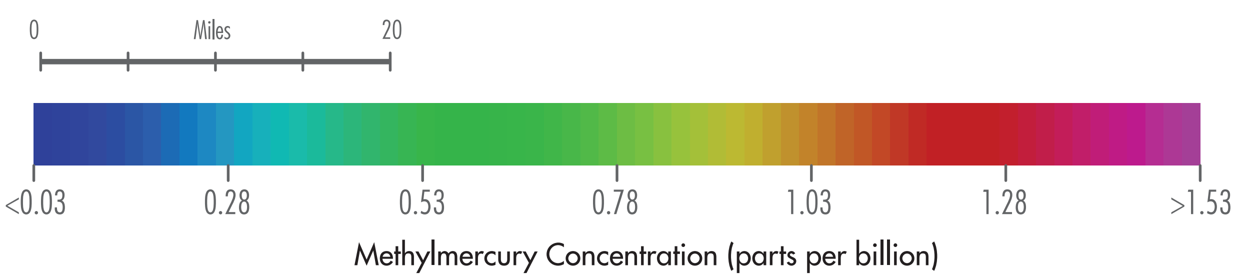
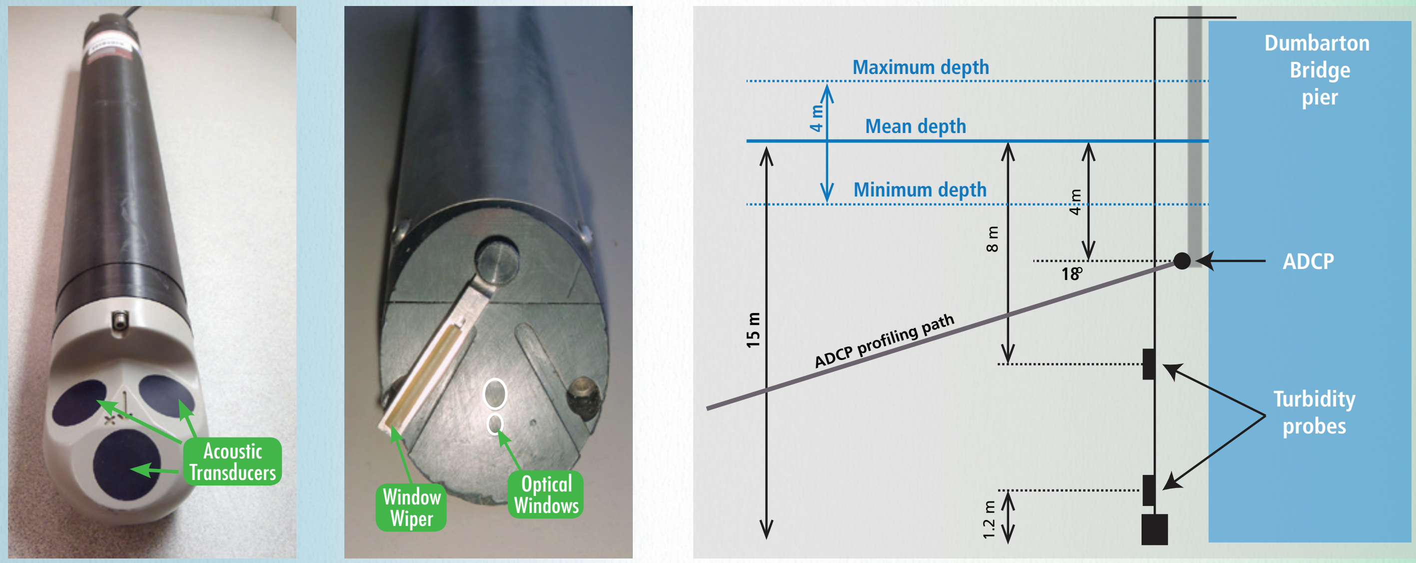



**Figure 3.**

**Concentrations of many pollutants, such as methylmercury (in parts per billion, ppb), are higher in sediment samples from South Bay and Lower South Bay than in the northern portions of the Bay.** The circles represent random sites and the diamonds represent fixed historic stations sampled during the wet season in 2012. Contour colors represent concentrations measured at random stations during the dry season sampling from 2002-2009 and 2011. Graphic is from San Francisco Estuary Institute (2013): The Pulse of the Bay: Contaminants of Emerging Concern. SFEI Contribution 701, San Francisco Estuary Institute, Richmond, CA.




## Figure 4.

**LEFT:** An acoustic Doppler current profiler (ADCP) measured water speed and direction.

**CENTER:** An optical turbidity probe measured turbidity, a surrogate for direct measurements of suspended-sediment concentrations.

**RIGHT:** A schematic of how the instruments were deployed on the Dumbarton Bridge.

# MEASUREMENTS AT THE DUMBARTON BRIDGE

Continuous measurements of water flow and suspended-sediment concentrations at the Dumbarton Bridge were made during water years 2009, 2010, and 2011. Studies of water and sediment flow are generally conducted over "water years," which begin with the start of the California rainy season on October 1 and end on September 30. Water years are named for the years in which they end.

Water flow was measured with an acoustic Doppler current profiler (ADCP), an instrument that uses reflected sound waves and changes in frequency of those waves to determine the speed and direction of flow (**FIGURE 4**). Suspended-sediment concentrations were determined from optical turbidity sensors, which measure the strength of light reflecting off particles suspended in the water column. The instrumentation is not sensitive to living phytoplankton, so their presence does not bias the results. The continuous light-based turbidity measurements were calibrated with direct measurements of suspended-sediment concentrations in water samples from the site. Direct measurements involved taking water samples, filtering them, and weighing the remaining material.

USGS established its ADCP water-flow monitoring station on one of the central bridge pilings. The ADCP was deployed near the water surface and measured flow in the water column. Two optical turbidity probes were deployed at the same site, one near the bottom and one at mid-depth. Scientists made periodic measurements taken from boats to calibrate both the flow and turbidity measurements. Together, the water flow and turbidity measurements were used to develop a time-series of estimates of the mass of suspended-sediment passing either southward or northward under the Bridge.

SAMPLING CREW INSTALLING EQUIPMENT. PHOTOGRAPH BY AMBER POWELL.

# WATER FLOW VARIES WITH TIDE

The water-flow measurements clearly showed the flow of water under the Dumbarton Bridge, including the changes brought with the two high tides and two low tides that occur each day in San Francisco Bay (**FIGURE 5**). The slowest flows, slack water, occurred near high and low tides, and the maximum velocities occurred approximately at the mid-point between high and low tides. The measurements also documented the differences in flows between spring tides, those highest tides that occur during or just after the new and full moons, and the lower, neap tides, which occur during the first and last quarter moons.

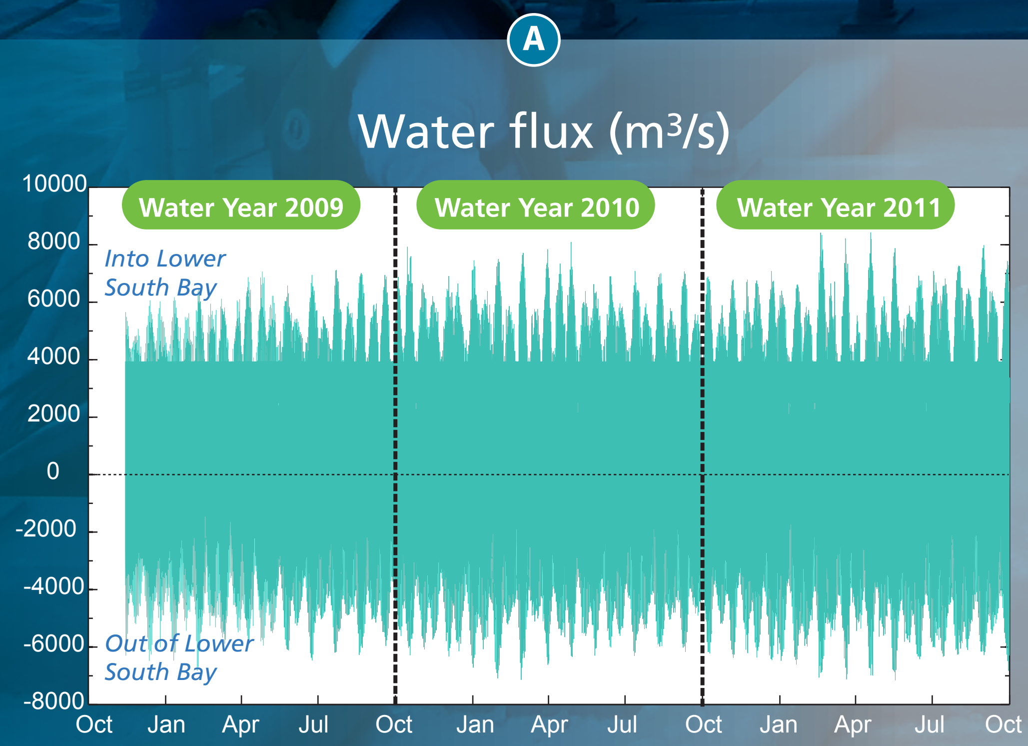


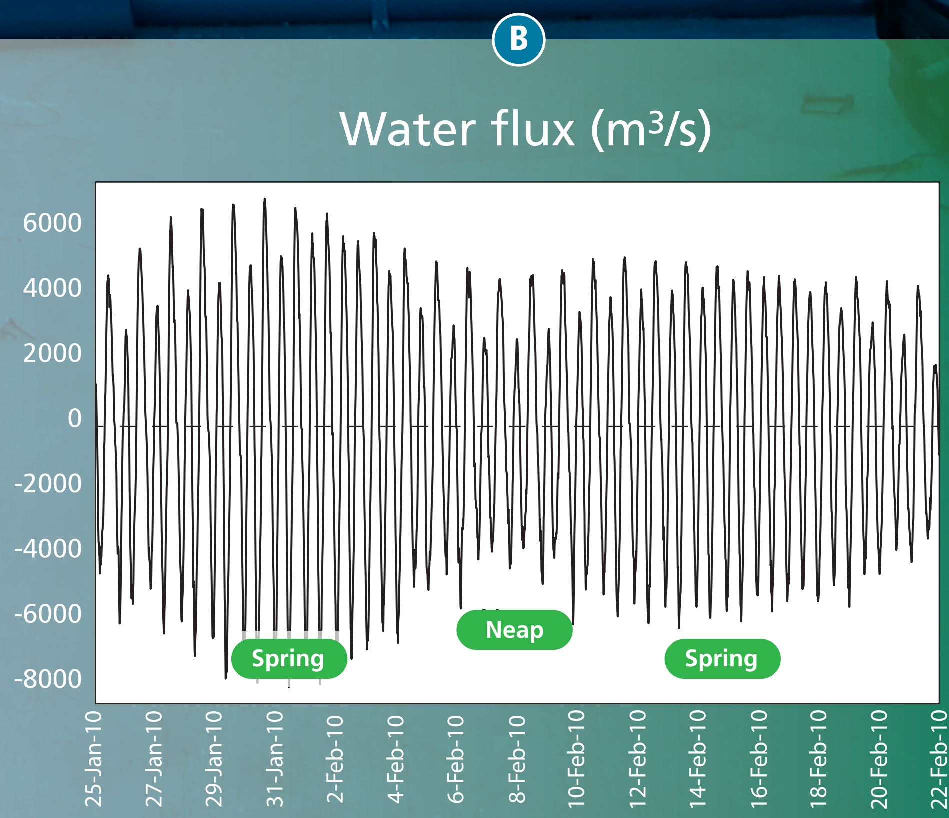

Figure 5.

**Water flow measurements showed the direction and amount of flow under the Dumbarton Bridge.** The flow direction changes twice each day because of the tide.

**A:** Positive values indicate flow from north to south into Lower South Bay, and negative values indicate flow from south to north out of Lower South Bay. The blue line shows the continuous measurements made by the ADCP on the bridge piling.

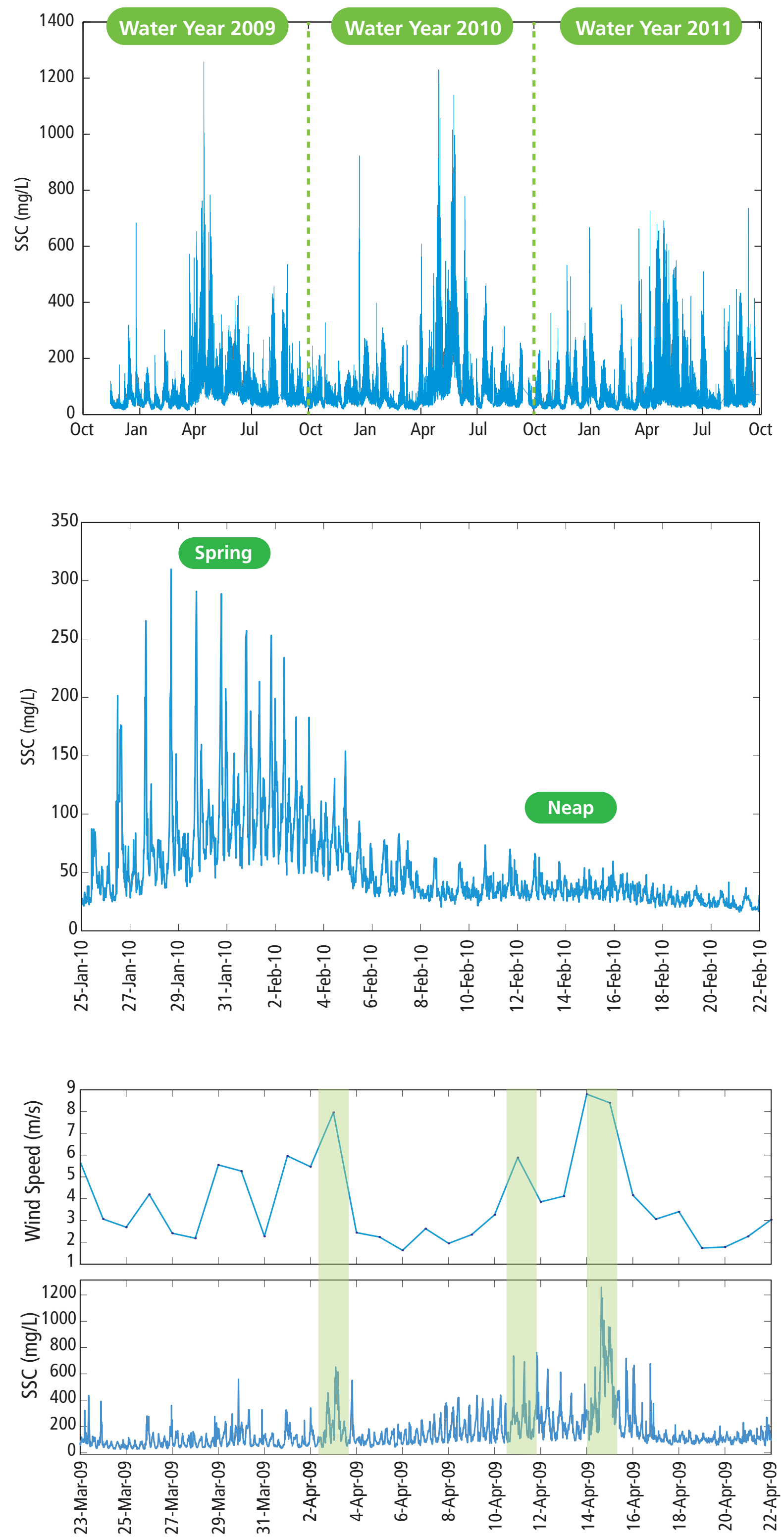
**B:** A close-up of one month of data from early 2010, showing the greater water flows during spring tides.

SAMPLNG CREW ON BRIDGE PILING.
PHOTOGRAPH BY KURT WEIDICH.



# SUSPENDED-SEDIMENT CONCENTRATIONS ARE HIGHLY VARIABLE

The turbidity measurements showed highly varying concentrations of suspended sediment in the water column, with the highest concentrations in April and May of each water year (**FIGURE 6**). Concentrations were higher during spring tides than neap tides, because the spring tides are bigger, have higher flows (**FIGURE 5**), and can resuspend more sediment. Strong winds can create larger waves, which lead to higher sediment concentrations from wind-wave resuspension of bottom sediment. Overall, the winds and the tides appear more important to causing high sediment concentrations in Lower South Bay than freshwater flow.




## Figure 6.

**Turbidity measurements provided a record of suspended-sediment concentrations (SSC) at the Dumbarton Bridge.**

**TOP:** Continuous SSC throughout water years 2009 - 2011, SSC were variable, with highest concentrations in the spring.

**MIDDLE:** SSC were greater during spring tides than during neap tides, as seen in a series of measurements in January and February 2010.

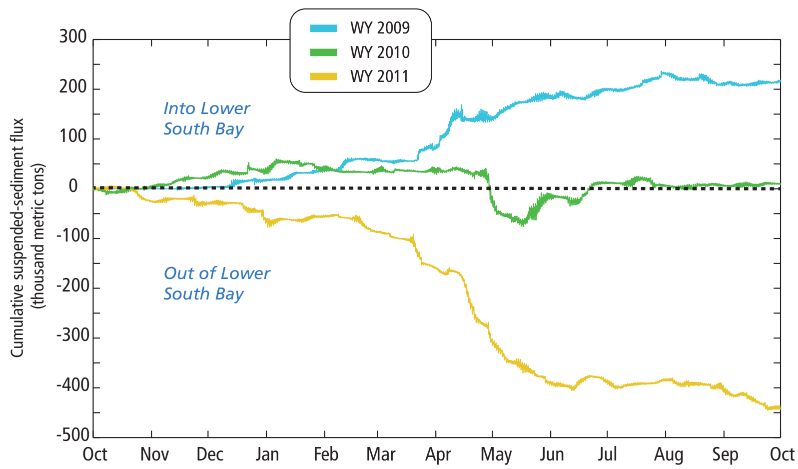
**BOTTOM:** Periods with especially strong winds (blue bands) corresponded to periods with higher SSC.

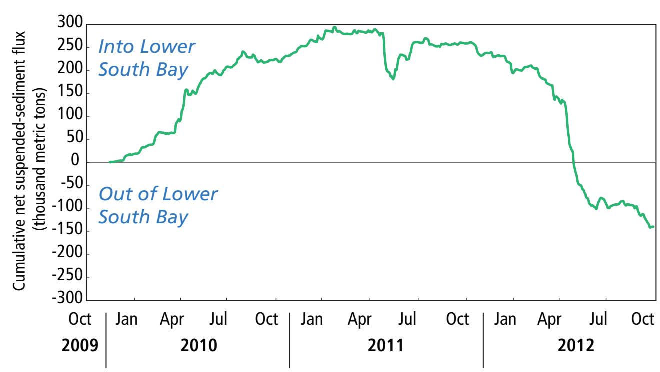
# NET SEDIMENT FLUX

Water years 2009 and 2010 had a net southward flux of suspended sediment from the main body of South Bay to Lower South Bay, while there was a net northward flux of sediment in water year 2011 (**FIGURE 7**). The results were particularly compelling in water year 2009, when the net movement into Lower South Bay totaled about 220,000 metric tons (243,000 tons) of sediment, while there was a gain of 35,000 metric tons (39,000 tons) in 2010. In contrast, the Lower South Bay net sediment loss in water year 2011 was about 400,000 metric tons (441,000 tons). Cumulatively, when net sediment movement is calculated over the three years of the study, more sediment moved from south to north past the Dumbarton Bridge and out of Lower South Bay than moved in the other direction, into Lower South Bay. The net flux over the three years of the study was 145,000 metric tons (160,000 tons) of sediment out of Lower South Bay. Given the short three-year period of this study and the big differences in weather patterns seen year to year in this part of California, the net direction of sediment movement computed for this study may not reflect the net direction of sediment movement in the long term.

In all years, the greatest fluxes occurred during a brief period in the spring: in April of water year 2009 and late April and May of water year 2010 and 2011. The direction of movement during these periods, southward in 2009 and 2010 but northward in 2011, may have been influenced by differences in weather patterns. The spring periods in 2010 and 2011 were unusually rainy, lowering the salinity in Central Bay, and creating a strong salinity gradient, with higher salinity in the south and lower salinity in the north. Research conducted by the USGS in the 1970s and 1980s showed that these conditions flush water out of South Bay, but how these changes in freshwater inputs and salinity affect sediment flux in the Bay is not fully understood.

Overall, the studies found that the sediment flux past Dumbarton Bridge is much larger than the inputs from the major tributaries to Lower South Bay, the Guadalupe River and Coyote Creek (**TABLE 1**). These findings are critically important to planning for the South Bay Salt Pond Restoration Project, and they suggest that managers might compensate for the sediment deficit by timing the openings of ponds to tidal action during years of lower precipitation and more southerly sediment flux supplying Lower South Bay. The results are also important to understanding the movement of contaminants between Central and South Bay.




## Figure 7.

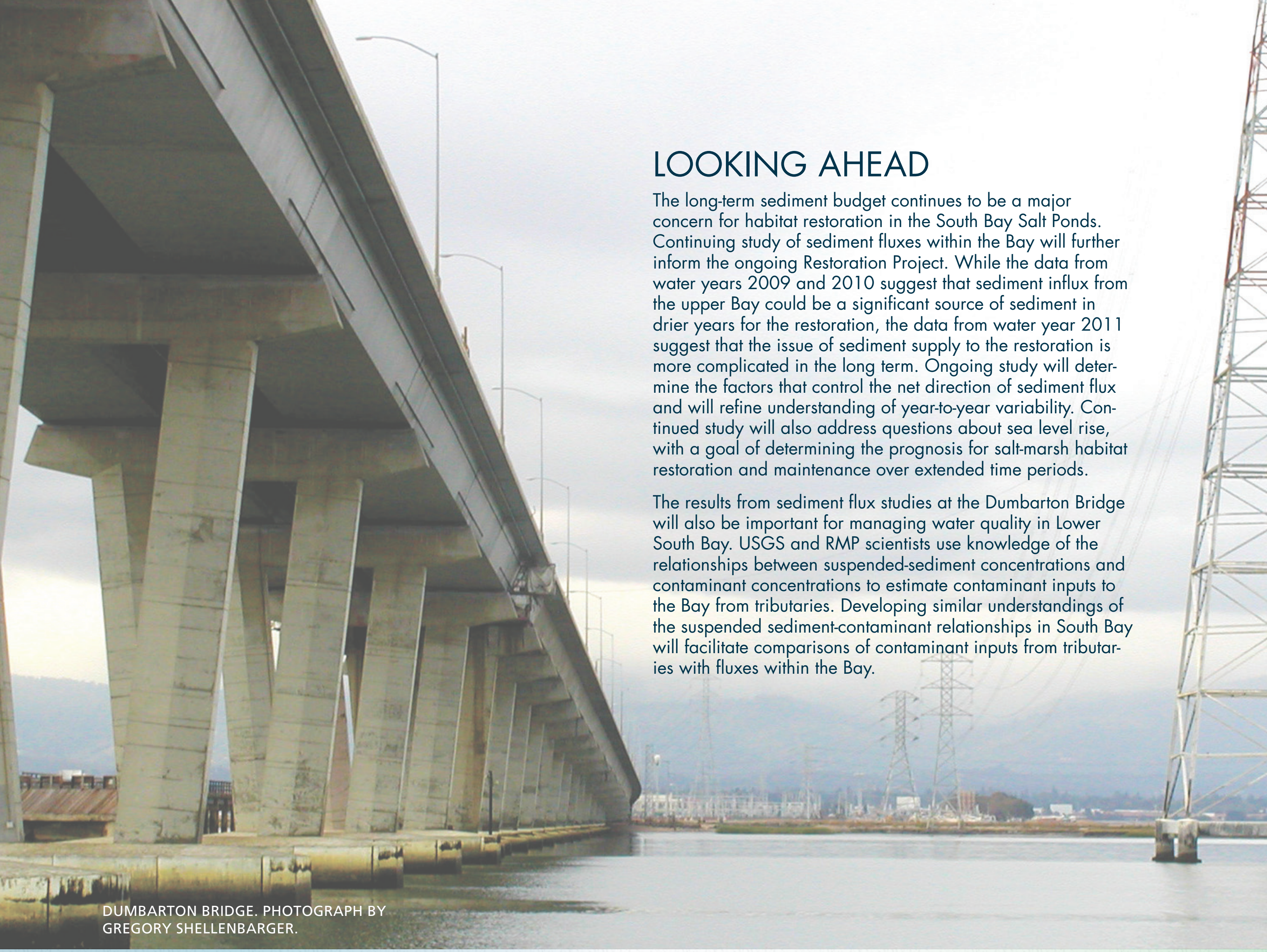
**TOP: The cumulative flux of suspended sediment at the Dumbarton Bridge in water years 2009, 2010, and 2011.** A positive flux indicates the net movement was into Lower South Bay.

**BOTTOM: The cumulative net suspended-sediment flux past the Dumbarton Bridge.** These results are for the net sediment budget and include sediment coming from the tributaries and wastewater treatment plants in Lower South Bay, as well as the sediment passing the bridge.

## Table 1.

**Wet season (October 1 through April 30) sediment fluxes to Lower South Bay from the Guadalupe River, Coyote Creek, and the Dumbarton Bridge and annual net flux for the Lower South Bay.** (Data from the Guadalupe River and Coyote Creek are collected only during the rainy season. Positive values are fluxes into Lower South Bay. All values in metric tons.)

| | WET SEASON SEDIMENT FLUX TO LOWER SOUTH BAY | | | ANNUAL NET SEDIMENT FLUX |
|---|---|---|---|---|
| | Guadalupe River | Coyote Creek | Dumbarton Bridge | Lower South Bay |
| Water Year 2009 | 2,000 | 2,700 | 140,000 | 220,000 |
| Water Year 2010 | 7,600 | 5,300 | -23,000 | 35,000 |
| Water Year 2011 | 12,000 | 11,000 | -310,000 | -400,000 |



## LOOKING AHEAD

The long-term sediment budget continues to be a major concern for habitat restoration in the South Bay Salt Ponds. Continuing study of sediment fluxes within the Bay will further inform the ongoing Restoration Project. While the data from water years 2009 and 2010 suggest that sediment influx from the upper Bay could be a significant source of sediment in drier years for the restoration, the data from water year 2011 suggest that the issue of sediment supply to the restoration is more complicated in the long term. Ongoing study will determine the factors that control the net direction of sediment flux and will refine understanding of year-to-year variability. Continued study will also address questions about sea level rise, with a goal of determining the prognosis for salt-marsh habitat restoration and maintenance over extended time periods.

The results from sediment flux studies at the Dumbarton Bridge will also be important for managing water quality in Lower South Bay. USGS and RMP scientists use knowledge of the relationships between suspended-sediment concentrations and contaminant concentrations to estimate contaminant inputs to the Bay from tributaries. Developing similar understandings of the suspended sediment-contaminant relationships in South Bay will facilitate comparisons of contaminant inputs from tributaries with fluxes within the Bay.

DUMBARTON BRIDGE. PHOTOGRAPH BY GREGORY SHELLENBARGER.

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## For More Information

For additional information on this study and more details about the results, please see:Shellenbarger, G.G., S.A. Wright, and D.H. Schoellhamer. 2013. A sediment budget for the southern reach in San Francisco Bay, CA: implications for habitat restoration. Marine Geology, 345: 281-293. The article can be found here: http://ca.water.usgs.gov/pubs/2013/ShellenbargerEtAl2013.html


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