RMP 2015

THE PULSE OF THE BAY

The State of Bay Water Quality: 2015 and 2065

COVER IMAGE:
Vision of a Bay Area City in 2065.
Illustration by Linda Wanczyk.

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RMP 2015

THE PULSE OF THE BAY

The State of Bay Water Quality: 2015 and 2065

A REPORT OF
THE REGIONAL MONITORING PROGRAM
FOR WATER QUALITY IN SAN FRANCISCO BAY

Overview

This edition of *The Pulse of the Bay* is a companion to the 2015 *State of the Estuary Report*. A water quality section of the *State of the Estuary Report* assesses our progress in meeting the Clean Water Act goals of waters that are swimmable, fishable, and safe for aquatic life. *The Pulse* provides a closer look at the state of San Francisco Bay water quality in 2015 and progress made since the *State of the Bay Report* in 2011. This *Pulse* also peers into the crystal ball at what the condition of Bay water might be 50 years from now.

The Current State of Bay Water Quality

On the good-fair-poor scale used in the *State of the Estuary Report*, Bay water quality in 2015 is good in regard to being safe for swimming, and fair in terms of being safe for fishing and aquatic life.

- Water quality conditions for swimming were excellent in 2013 at most Bay beaches. However, conditions were poor at two of 28 beaches in summer and six of 22 in wet weather. The San Francisco Bay Regional Water Board is developing a control plan for six beaches that have persistent pathogen contamination.

- The California Office of Environmental Health Hazard Assessment advises limited consumption of most popular Bay fish species (e.g., striped bass and California halibut) due to contamination from two legacy pollutants (mercury and PCBs). There has been no indication of declines in concentrations of these contaminants in fish over the past 20 years. Substantial efforts are underway, however, to reduce inputs of mercury and PCBs to the Bay.

- The chemical quality of the Bay as habitat for the animal and plant species that live in or depend upon it is fair, but improving. Hundreds of chemicals have been measured and are below thresholds for concern. A few contaminants (mercury, invasive species, and trash), however, are significant and persistent problems. Recent improvement has been achieved for PBDEs (flame retardants) and copper, and additional improvement is expected for invasive species, trash, and PFOS (a component of stain repellants). Many potentially harmful chemicals have yet to be assessed.

Two important new initiatives that couple water quality management and monitoring have taken shape in the past few years focused on nutrients and emerging contaminants. To address possible adverse nutrient impacts in the Bay, the San Francisco Bay Water Board worked collaboratively with stakeholders to develop the San Francisco Bay Nutrient Management Strategy in 2012. Implementation of the Strategy is underway, building the scientific understanding to support well-informed nutrient management decisions. In 2013, the Water Board, again in concert with stakeholders, developed a tiered, risk-based framework to guide management and monitoring of emerging contaminants.

In a similar vein as the 2013 Pulse, which provided profiles of contaminants of emerging concern, this year's Pulse presents individual summaries of recent advances in the science and management of the highest priority contaminants (pages 30-61). Interesting patterns are emerging from the monitoring conducted by the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP) and other programs.

- Concerns that tidal marsh restoration could exacerbate the Bay's mercury problem appear to be diminishing. Recent monitoring of marsh restoration projects in the North Bay and South Bay indicates that opening salt ponds to tidal action has not caused local increases in food web mercury (page 36).

- PCB concentrations in Bay sediment appear to be trending downward in Central Bay and South Bay, but upward in Lower South Bay. Recent monitoring has revealed a region with relatively high concentrations along the shoreline of southwestern Central Bay and western South Bay (page 39).

Miller/Knox Regional Shoreline, Richmond. Photograph by Shira Bezalel.

- Increases in chlorophyll concentrations in the South Bay in late summer from 1995 to 2005 raised concern that the Bay's historic resilience to high nutrient concentrations may be weakening. Concentrations have leveled off and fallen a bit since 2005 (page 43).

- Low levels of algal toxins from upstream (microcystin) and the ocean (domoic acid) are pervasive in the Bay (page 47). Preliminary data indicate that concentrations are well below thresholds for toxic effects, but more thorough monitoring is needed.

- A decade of RMP monitoring has documented declines in toxic flame retardants known as PBDEs following a halt in US production (page 54).

- Bay wildlife were analyzed for previously unmonitored contaminants using a non-targeted analytical technique. Bay mussel and harbor seal samples contained five contaminants not previously identified in Bay wildlife, but most of the Bay chemical contamination was from high priority contaminants that the RMP already monitors (page 55).

- Concentrations of PAHs (toxicants related to the use and combustion of fossil fuels) in Bay sediment may be trending upward (page 58).

Bay Water Quality in 50 Years

Based on interviews with six local experts (page 18), 50 years from now it can be expected that Bay Area sources of today's pollutants of concern will be under robust control and that major hotspots will have been cleaned up. Other likely changes include significant reductions in water flows and contaminant loads into the Bay as municipal wastewater and stormwater are increasingly conserved and used as a water supply; alterations in flows into the Estuary, the spatial extent of the Estuary, water movement, and water chemistry due to climate change; and changes due to new technologies including enhancements in water quality monitoring but also potential threats posed by new materials used in energy generation, transportation, and other sectors.

With the continued diligence of managers and scientists, and sustained support from policy-makers and the public, Bay water quality will remain on a path of improvement in reducing the pollutants of today, and better recognition and action to curtail the pollutants of tomorrow before they make the Bay less safe for swimming, fishing, or aquatic life. ■

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For PDF versions of all Pulses, go to: www.sfei.org/programs/pulse-bay

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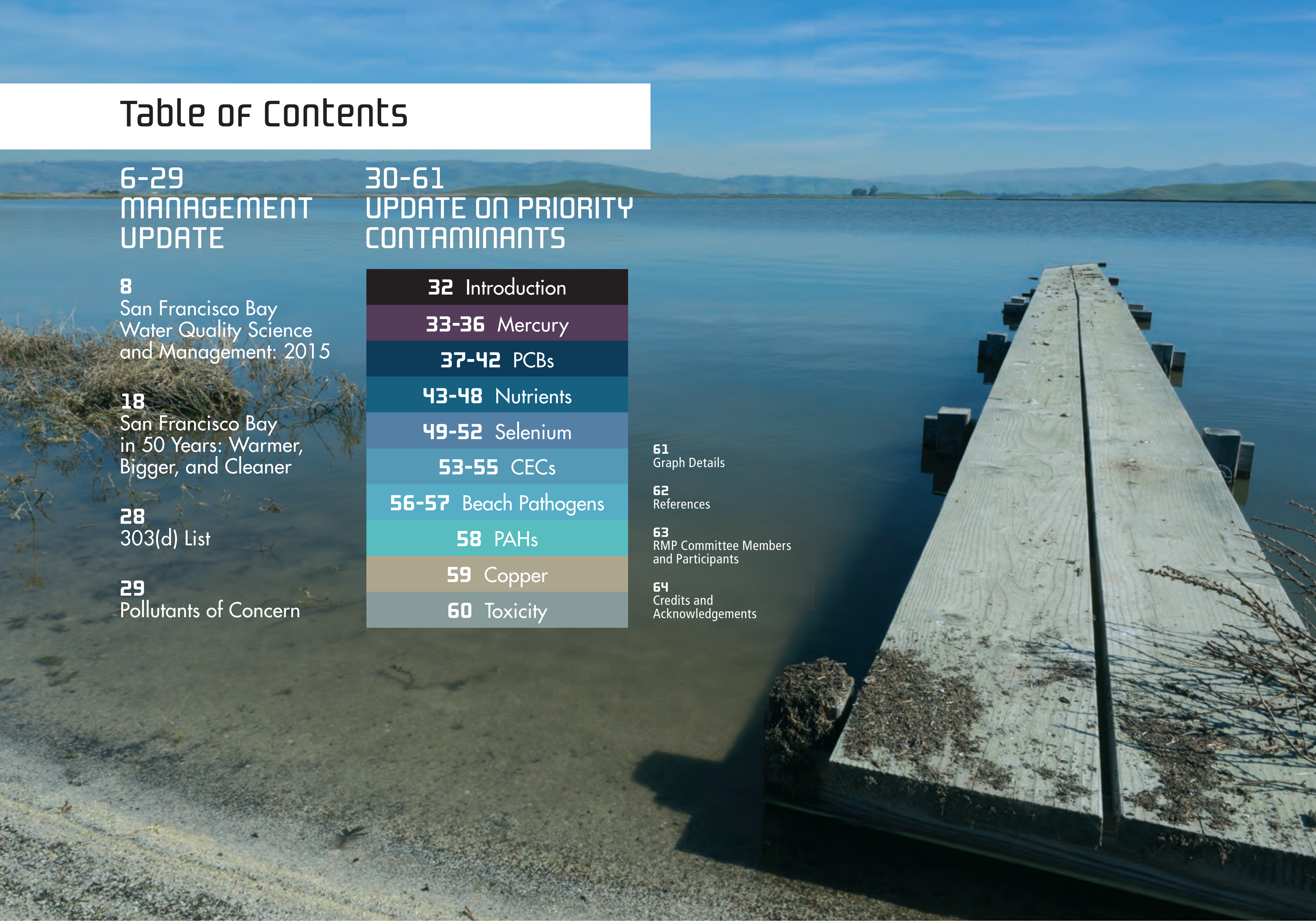


Coyote Hills Regional Park, Fremont. Photograph by Shira Bezalel.

MANAGEMENT UPDATE

Point Isabel, Richmond. Photograph by Shira Bezalel.

San Francisco Bay Water Quality Science and Management: 2015

by Jay Davis (jay@sfei.org) and Rebecca Sutton,
San Fancisco Estuary Institute

HIGHLIGHTS

This edition of *The Pulse of the Bay* is a companion to the 2015 *State of the Estuary Report*, providing a closer look at the state of Bay water quality in 2015

The Report examined whether Estuary waters are clean enough to be safe for fishing, for swimming, and to provide healthy habitat for aquatic life

The status for fishing is fair and there has been no indication of improvement since 1994

Water quality conditions are excellent for swimming at most Bay beaches, however conditions are poor at 7% of beaches in summer and 27% in wet weather

The quality of Bay water as habitat for aquatic life is fair, but there have been recent noteworthy improvements, especially for PBDEs

Significant progress has occurred over the last four years, particularly with regard to contaminants of emerging concern, nutrients, and loadings of legacy contaminants from urban runoff

Point Richmond. Photograph by Shira Bezalel.

The State of Bay Water Quality

Clean water is essential to the health of the Bay ecosystem and to many of the benefits the Bay provides to Bay Area residents and visitors. Protecting and restoring Bay water quality is a priority for the region, as evidenced by the billions of dollars that have been, and continue to be, invested in management of municipal wastewater and other pollutant sources.

The San Francisco Estuary Partnership (SFEP), a coalition of resource agencies, non-profit organizations, citizens, and scientists, has published a 2015 *State of the Estuary Report* (SFEP 2015). The report summarizes progress in attaining established management goals for San Francisco Bay and the Sacramento-San Joaquin Delta relating to habitat, water flow and quality, living resources, ecological processes, and stewardship. The report is a sequel to SFEP's *State of the Bay Report* published in 2011 (SFEP 2011), with the geographic scope expanded to include the Delta, and thus the entire San Francisco Estuary. The water quality section of the *State of the Estuary Report* assesses how well the Clean Water Act goals of waters that are fishable, swimmable, and safe for aquatic life are being met (Figure 1).

This edition of *The Pulse of the Bay* is a companion to the *State of the Estuary Report*, providing a closer look at the state of San Francisco Bay water quality in 2015 and progress made since the *State of the Bay Report* in 2011.

In terms of a high level summary, status and trends in the condition of the Bay in regard to these three questions have not changed since 2011 (Figure 1). However, many significant advances in understanding and managing water pollutants have been made since the last State of the Bay assessment in 2011. These advances are highlighted later in this article and in the Priority Contaminant Updates (pages 30-61).

Figure 1. Summary of Bay water quality. Additional information available in the State of the Estuary Report and its supporting materials.

IS THE BAY SAFE FOR AQUATIC LIFE?

STATUS

FAIR

TREND

IMPROVING

DETAILS

Bay water quality is much better than 40 years ago, but the rate of improvement has slowed. Mercury, invasive species, and trash are still problems. Improvement has been achieved for PBDEs and copper, and is expected for invasive species, trash, and PFOS. Hundreds of chemicals have been measured and are below thresholds for concern. Many potentially harmful chemicals have yet to be assessed.

IS THE BAY SAFE FOR FISHING?

STATUS

FAIR

TREND

NO CHANGE

DETAILS

Limited consumption of most popular Bay fish species is advised due to contamination from two legacy pollutants (mercury and PCBs). Routine monitoring in place since 1994 has shown no signs of decline in these contaminants.

IS THE BAY SAFE FOR SWIMMING?

STATUS

GOOD

TREND

NO CHANGE

DETAILS

Conditions are excellent at most Bay beaches. However, conditions are poor at 7% of beaches in summer and 27% in wet weather.

Is the Bay Safe for Aquatic Life?

The Bay remains in fair condition in terms of providing clean habitat that supports abundant, diverse communities of all of the animal and plant species that live in or depend upon the Bay, including algae, zooplankton, macroinvertebrates, fish, aquatic birds, and marine mammals.

Concentrations of the vast majority of regulated pollutants are below levels of concern, and many others that are not regulated have been screened and also found to be below levels of concern (Sidebar, page 12).

Is the Bay Safe for Fishing?

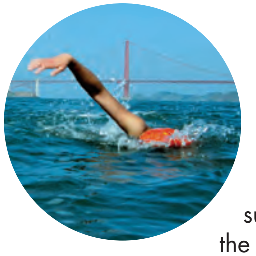
The Bay is also in fair condition in regard to being a source of fish that are safe to eat.

Some species, such as Chinook salmon and jacksmelt, are safe for consumption. Many pollutants are below thresholds for concern across all fish species, including arsenic, cadmium, chlorpyrifos, diazinon, dieldrin, DDTs, PAHs, PBDEs, and selenium. However, the California Office of Environmental Health Hazard Assessment (OEHHA) advises limited consumption of many popular Bay fish species due primarily to contamination from two legacy pollutants: mercury and PCBs. Mercury and PCB concentrations in some Bay fish species pose health risks, especially to fetuses and to children up through age 17. Methylmercury, the toxic form of mercury, can have detrimental impacts on brain development in fetuses and children, including potential decreases in learning ability, language skills, attention, and memory. It is especially important for women who are pregnant or breastfeeding to follow OEHHA's consumption guidelines. The primary concern with PCBs is that they can cause cancer.

The degree of contamination varies by species. Striped bass have relatively high concentrations of mercury while jacksmelt are relatively low in this contaminant. Shiner surfperch have relatively high concentrations of PCBs, and California halibut have relatively low concentrations. The consumption guidelines for the Bay highlight the key differences among species to allow fish consumers to reduce their exposure. For example, the OEHHA guidelines indicate that PCB concentrations in one group of species - surfperch - are high enough that they should not be eaten at all.

PCBs have not shown signs of decline over the past 20 years. For mercury, the data go back even further, and suggest no decline over the past 45 years. Once persistent pollutants like PCBs and mercury enter the Bay, they become mixed into the bottom sediment and trapped in the ecosystem for decades, allowing them to seep into the base of the food web, transfer up the food chain, and reach concentrations that threaten sensitive life stages of humans and wildlife.

American avocet. Photograph by Don DeBold.



Is the Bay Safe for Swimming?

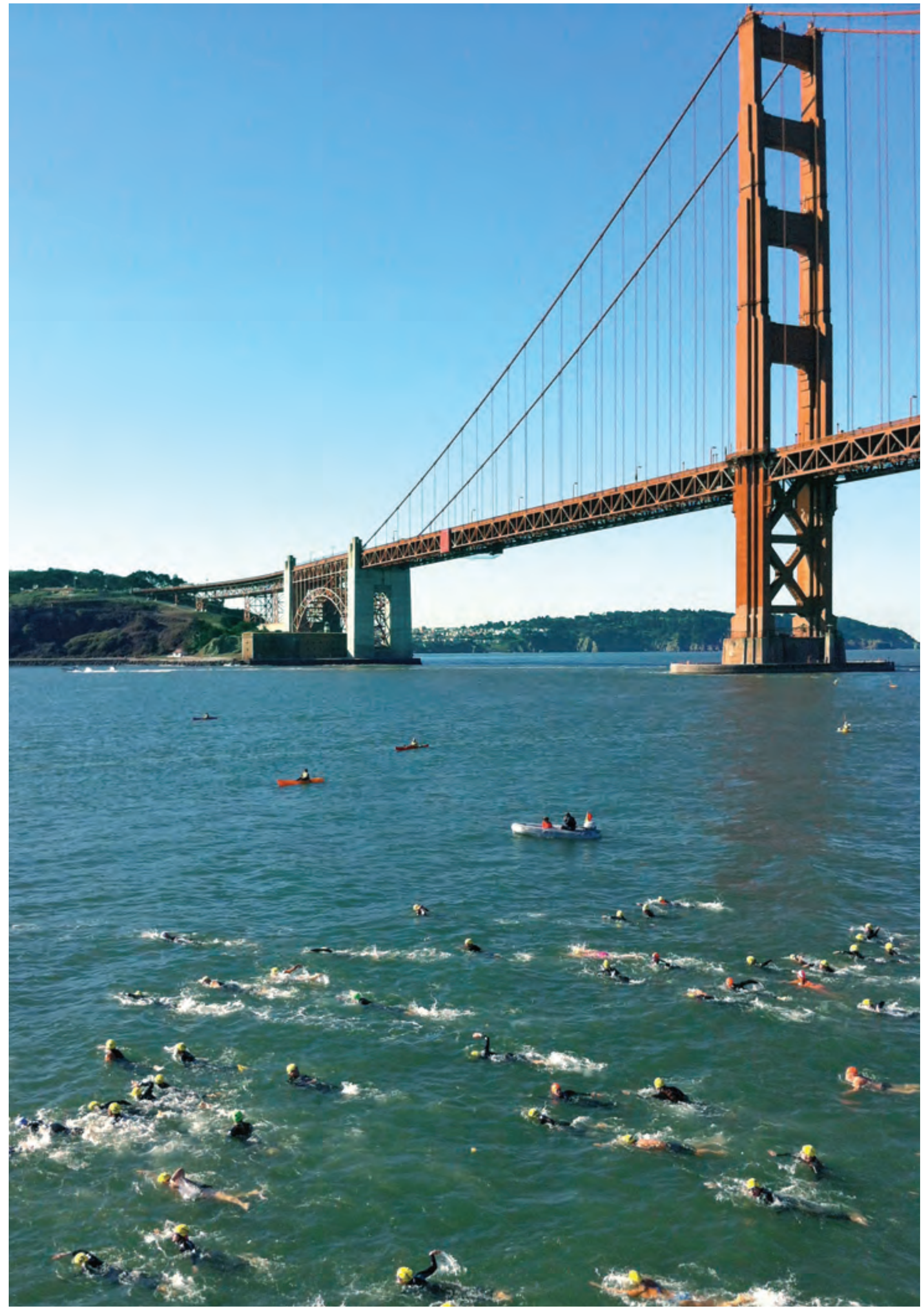
The Bay is generally a safe place to swim, wade, surf, windsurf, or enjoy other forms of recreation in the water. There are a few locations, however, that are exceptions to this general rule.

Pathogens (microscopic organisms that can cause disease or illness) are found in waste from humans and other warm-blooded animals, and can pose health risks to people who come into contact with contaminated waters. "Fecal indicator bacteria" are monitored as a proxy for pathogen abundance on a weekly basis at 28 popular beaches around the Bay (pages 56-57).

In 2013, conditions were excellent at 79% (22 of 28) of beaches in the summer, and at a slightly lower percentage of beaches (64%, 14 of 22) in wet weather.

Fecal indicator bacteria measurements suggest that some beaches have problematic concentrations of pathogens, however. Conditions are poor at 7% of beaches in summer and 27% in wet weather. Six Bay beaches are on the 303(d) List of impaired water bodies because fecal indicator bacteria exceed water quality standards, and a process to develop a TMDL to address these impairments began in 2013.

The assessment of whether the Bay is safe for swimming is based on grades given to popular Bay beaches by Heal the Bay, a Santa Monica-based non-profit that translates fecal indicator bacteria data into Beach Report Cards. The Bay-wide average summer grade has been fairly constant over the past five years, with the highest grades in the latest two years of sampling. Successful implementation of the TMDL can be expected to improve conditions at the beaches with higher fecal indicator bacteria concentrations, and would further improve the Bay-wide grade. Management actions will be considered for the major pathways of pathogen contamination: sanitary sewer collection systems, urban runoff, pets, and boats.



Annual Bay swim for Swim Across America, raising money and awareness for cancer research, prevention, and treatment: www.swimacrossamerica.org. Photograph by Jay Davis.

The Good News

The Regional Monitoring Program for Water Quality in San Francisco Bay (RMP) has monitored hundreds of contaminants in Bay water, sediment, and aquatic organisms. Out of all of these, only a handful consistently exceed established water quality objectives and represent clear problems (see HIGH CONCERN list, next page). Control plans for these contaminants are in place or in development.

Another small group of contaminants and parameters approach or occasionally exceed water quality objectives or published thresholds for toxic effects (see MODERATE CONCERN list, next page). For most of these contaminants, control plans are either in place or in development. A few members of this group are contaminants of emerging concern (CECs) for which objectives have not been established. For these chemicals the Water Board is establishing action plans that include aggressive pollution prevention and low-cost control actions.

The largest group, by far, consists of contaminants that do not approach or exceed water quality objectives or published effect thresholds (see LOW CONCERN list, next page).

Golden Gate Bridge. Photograph by Jay Davis.

Water quality objectives have been established for a list of over 100 Priority Pollutants identified by the US Environmental Protection Agency (USEPA), and all of these pollutants have been monitored by the RMP. A few of the pollutants on the USEPA list, such as mercury and PCBs, qualify for the problematic categories mentioned above. Most of them, however, are not present in the Bay at concentrations that threaten aquatic life. Some of these pollutants (e.g., silver, chlorpyrifos, and diazinon) are former problems that have been controlled. Others (e.g., nickel) were formerly considered potential problems but improved information has resolved the concern. Many of the Priority Pollutants are routinely monitored by the RMP. Less frequently, a comprehensive evaluation of the entire list is performed - most recently in 2002 and 2003. The RMP will conduct another comprehensive evaluation in 2015.

For CECs, water quality objectives have yet to be developed, so concentrations are compared to published effects thresholds, if those are available. For the past decade, the RMP has been making a concerted effort to identify problem CECs. Bay water quality managers and RMP scientists have developed a tiered scheme for prioritizing CECs to guide decisions on monitoring and management (page 53). A large number of CECs have been monitored in the Bay and found to be of low concern, where concentrations are well below known thresholds for adverse effects. Some of these contaminants may rise to a higher level of concern as improved information becomes available on their occurrence and modes of toxic action. Overall it is encouraging, however, that extensive surveillance for CECs has so far only identified a few chemicals of significant concern.

Classification of Bay Contaminants

HIGH CONCERN

Mercury • PCBs • Pathogens • Dioxins

MODERATE CONCERN

Selenium • DDT • Dieldrin • PFOS • Fipronil • Chlordane • PAHs • PBDEs • Nonylphenol

LOW CONCERN

USEPA Priority Pollutants

Acrolein • Acrylonitrile • Benzene • Benzidine • Carbon tetrachloride • Chlorobenzene • 1,2,4-trichlorobenzene • Hexachlorobenzene • 1,2-dichloroethane • 1,1,1-trichloroethane • Hexachloroethane • 1,1-dichloroethane • 1,1,2-trichloroethane • 1,1,2,2-tetrachloroethane • Chloroethane • Bis(2-chloroethyl) ether • 2-chloroethyl vinyl ethers • 2-chloronaphthalene • 2,4,6-trichlorophenol • Parachlorometa cresol • Chloroform • 2-chlorophenol • 1,2-dichlorobenzene • 1,3-dichlorobenzene • 1,4-dichlorobenzene • 3,3-dichlorobenzidine • 1,1-dichloroethylene • 1,2-trans-dichloroethylene • 2,4-dichlorophenol • 1,2-dichloropropane • 1,3-dichloropropylene • 2,4-dimethylphenol • 2,4-dinitrotoluene • 2,6-dinitrotoluene • 1,2-diphenylhydrazine • Ethylbenzene • Fluoranthene • 4-chlorophenyl phenyl ether • 4-bromophenyl phenyl ether • Bis(2-chloroisopropyl) ether • Bis(2-chloroethoxy) methane • Methylene chloride • Methyl chloride • Methyl bromide • Bromoform • Dichlorobromomethane • Chlorodibromomethane • Hexachlorobutadiene • Hexachlorocyclopentadiene • Isophorone • Naphthalene • Nitrobenzene • 2-nitrophenol • 4-nitrophenol • 2,4-dinitrophenol • 4,6-dinitro-o-cresol • N-nitrosodimethylamine • N-nitrosodiphenylamine • N-nitrosodi-n-propylamine • Pentachlorophenol • Phenol • Di-n-butyl Phthalate • Di-n-octyl phthalate • Diethyl phthalate • Dimethyl phthalate • Tetrachloroethylene • Toluene • Trichloroethylene • Vinyl chloride • Aldrin • Alpha-endosulfan • Beta-endosulfan • Endosulfan sulfate • Endrin • Endrin aldehyde • Alpha-BHC • Beta-BHC • Gamma-BHC • Delta-BHC • Toxaphene • Antimony • Arsenic • Asbestos • Beryllium • Cadmium • Chromium • Copper • Cyanide • Lead • Nickel • Silver • Thallium • Zinc

Pharmaceuticals

Acetaminophen • Albuterol • Alprazolam • Amitriptyline • 10-hydroxy-amitriptyline • Amlodipine • Amphetamine • Atenolol • Atorvastatin • Azithromycin • Benzoylecgonine • Benztropine • Betamethasone • Caffeine • Carbadox • Carbamazepine • Cefotaxime • Cimetidine • Ciprofloxacin • Clarithromycin • Clinafloxacin • Clonidine • Cloxacillin • Cocaine • Codeine • Cotinine • Dehydronifedipine • Desmethyldiltiazem • Diazepam • Digoxigenin • Digoxin • Diltiazem • 1,7-Dimethylxanthine • Diphenhydramine • Enalapril • Enrofloxacin • Erythromycin-H20 • Flumequine • Fluocinonide • Fluoxetine • Fluticasone propionate • Furosemide • Gemfibrozil • Glipizide • Glyburide • Hydrochlorothiazide • Hydrocodone • Hydrocortisone • Ibuprofen • Ibuprofen, 2-hydroxy- • Lincomycin • Lomefloxacin • Meprobamate • Metformin • Methylprednisolone • Metoprolol • Miconazole • Naproxen • Norfloxacin • Norfluoxetine • Norgestimate • Norverapamil • Ofloxacin • Ormetoprim • Oxacillin • Oxolinic acid • Oxycodone • Paroxetine • Penicillin G • Penicillin V • Prednisolone • Prednisone • Promethazine • Propoxyphene • Propranolol • Ranitidine • Roxithromycin • Sarafloxacin • Sertraline • Simvastatin • Sulfachloropyridazine • Sulfadiazine • Sulfadimethoxine • Sulfamerazine • Sulfamethazine • Sulfamethizole • Sulfamethoxazole • Sulfanilamide • Sulfathiazole • Theophylline • Thiabendazole • Trenbolone • Trenbolone acetate • Triamterene • Trimethoprim • Tylosin • Valsartan • Verapamil • Virginiamycin • Warfarin

Pyrethroids*

Allethrin • Bifenthrin • Cyfluthrin • Cyhalothrin • Cypermethrin • Deltamethrin • Esfenvalerate/Fenvalerate • Fenpropathrin • Oxadiazon • Permethrin • Phenothrin • Phosmet • Resmethrin • Tetramethrin

Personal Care Product Ingredients

N,N-diethyl-m-toluamide (DEET) • Celestolide • Galaxolide • Tonalide • Versalide • Musk ambrette • Musk ketone • Musk moskene • Musk xylene • Di-n-butyl phthalate • Triclocarban • Triclosan • Octylphenol

Polybrominated dioxins and furans (PBDD/Fs)

1,3,7-TriBDD • 1,2,4,8-TeBDD • 2,3,7,8-TetraBDD • 1,2,3,7,8-PentaBDD • 1,2,3,4,7,8/1,2,3,6,7,8-HexaBDD • 1,2,3,7,8,9-HexaBDD • OctaBDD • 2,3,7,8-TetraBDF • 1,2,3,7,8-PentaBDF • 2,3,4,7,8-PentaBDF • 1,2,3,4,7,8-HexaBDF • 1,2,3,4,6,7,8-HeptaBDF • OctaBDF

Flame Retardants

Hexabromocyclododecane

* Pyrethroids are of low concern in the Bay, but high concern in Bay Area urban creeks

Significant Progress On Several Fronts

Significant progress in water quality monitoring and management has occurred over the last four years. Three primary areas of emphasis have been identification and tracking of contaminants of emerging concern, measuring loads of legacy contaminants from urban runoff, and assessment of the threat posed by the Bay's high nutrient concentrations.

Water Board staff are drafting Action Plans for the CECs identified as moderate concerns for the Bay: perfluorochemicals, PBDEs, nonylphenol ethoxylates, and the pesticide fipronil

Contaminants of Emerging Concern

The management and science of contaminants of emerging concern (CECs) is an area of dynamic development. CECs are unregulated chemicals that have the potential to enter the Bay and cause harm to humans and wildlife. Early identification of high-risk CECs and quick action to prevent pollution is an optimal and cost-effective strategy for protecting water quality.

A number of important steps forward in CEC management have been made at the local, state, and federal levels.

- In 2013, the Water Board, in concert with the RMP and local agencies, developed a tiered risk framework (page 53) to guide CEC management and monitoring efforts. Bay Area agencies have been implementing management actions locally and pursuing actions at the federal and state level that are consistent with the framework for more than ten years, including public education and outreach, local ordinances, regulations, and legislation.
- In 2013 the California Bureau of Home Furnishings revised key flammability standards to eliminate the need to add potentially harmful flame retardant chemicals to furniture and many baby products. An effort to re-examine a flammability standard for foam building insulation is also underway. Earlier efforts to address flame retardant pollution through an industry phase-out and state ban of a toxic flame retardant family, polybrominated diphenyl ethers (PBDEs), have resulted in declines in these contaminants in Bay wildlife and sediment. Extensive RMP monitoring of PBDEs in the Bay made this one of the best-documented examples of the decline of a CEC in an aquatic ecosystem in response to a major policy change.
- In 2012 the California Department of Pesticide Regulation restricted the ways professional applicators are allowed to apply pyrethroid insecticides around buildings. Together with special restrictions placed on bifenthrin (the most environmentally persistent pyrethroid), these regulations are expected to reduce pyrethroid-caused toxicity in rivers and streams by 80-90%.
- Local efforts to reduce pharmaceutical pollution through collection of unused medicines are growing. In 2015 Alameda County's ordinance requiring drug manufacturers to fund stewardship and disposal costs survived its final legal challenge. San Francisco, Santa Clara, San Mateo, and Marin counties have adopted similar ordinances. Meanwhile, changes to federal regulations may make voluntary collection projects easier to implement.
- California has also begun to implement a groundbreaking green chemistry approach to guide chemical and product manufacturers toward safer product design. The Department of Toxic Substance Control's Safer Consumer Products Regulations, established in 2013, define a process to evaluate whether there are safer alternatives to a chemical of concern in a product, and allow the agency to implement appropriate controls.
- The USEPA has proposed "significant new use rules" to limit reintroduction of harmful chemicals into commerce once they have been removed by industry. CECs that have been the subject of recently proposed rules include a detergent family called nonylphenol ethoxylates (2014), and the stain- and stick-resistant (e.g., Scotchgard and Teflon) perfluorochemical family (2015).

Looking to the future, efforts to reduce the harmful effects of CECs in the Bay will revolve around CEC Action Plans developed by the Water Board. Water Board staff are now drafting Action Plans for the CECs identified as moderate concerns for the Bay: perfluorochemicals, PBDEs, nonylphenol ethoxylates, and the pesticide fipronil. Potential policy changes at the state level, including actions to reduce use of flame retardants and pesticides, can aid local efforts. The RMP will provide the scientific support needed to develop CEC Action Plans and the management strategies of local stakeholders.

- In 2013 the RMP published a CEC Strategy (Sutton et al. 2013) that guides special studies on CECs, assuring continued focus on the issues of highest priority to the health of the Bay.
- RMP special studies to address data gaps regarding Bay CECs have included targeted monitoring of pharmaceuticals, flame retardants, perfluorochemicals and pesticides, and non-targeted monitoring to explore previously unidentified contaminants in Bay wildlife. Further details are provided on pages 53-55, and in the 2013 Pulse of the Bay (SFEI 2013).

Urban Runoff

Urban runoff is a primary focus of managers in their efforts to control legacy pollutants such as mercury and PCBs, trash, and other threats to Bay water quality. In 2009 the Water Board made a major stride forward in the management of urban runoff through the adoption of a Municipal Regional Stormwater Permit (MRP) that covers much of the Bay Area. From 2009 to 2014 county agencies and their partners conducted $10 million worth of loads monitoring and studies in addressing provisions of the MRP and made significant advances in understanding and managing urban runoff. Much of this work was performed as part of a $5 million project titled "Clean Watersheds for a Clean Bay (CW4CB)", primarily funded by USEPA and scheduled for completion in early 2016.

One major area of emphasis under the MRP has been pilot-scale evaluation of the effectiveness and costs of a variety of control measures, including:

- identification of source properties in five urban areas known to be hot zones for PCBs;
- enhanced street sweeping at three sites;
- street washing and pipe flushing at two sites;
- treatment retrofits at more than ten sites, including green infrastructure elements such as rain gardens and swales, vault-based filtration units, and tree wells (tree-containing catch basins that filter stormwater);
- diversion of stormwater to sewage treatment plants at five sites;
- investigation of PCBs in building materials; and
- exposure reduction through risk communication to fish consumers.

> All of this work on controls and monitoring has set the stage for the next iteration of the Municipal Regional Stormwater Permit ("MRP 2.0")

Significant actions have been taken to control trash, including installation of 4,000 capture devices that intercept debris from 20,000 acres, as well as outreach efforts to reduce trash generation.

Substantial progress has also been made under the MRP in establishing the knowledge base needed to manage urban runoff. Studies performed as part of the Regional Monitoring Program focused on improving estimates of regional loads to the Bay through intensive monitoring of contaminant exports from six watersheds and development of a regional modeling framework. Studies performed under CW4CB, the Regional Monitoring Program, and other projects have included regional surveys of contaminants in sediment and soil and other studies to support selection of watersheds for source tracking and piloting of management techniques.

All of this work on controls and monitoring has set the stage for the next iteration of the MRP ("MRP 2.0"). MRP 2.0 is under development in 2015 and will call for further advances in managing legacy contaminants, trash, pesticides, and other contaminants in urban runoff. In terms of control measures, MRP 2.0 is expected to emphasize implementation of the techniques that were piloted in the first permit term. Green infrastructure will be a particular priority, including the development of master plans across the region.

In support of MRP 2.0, the Regional Monitoring Program is shifting the emphasis of its tributary load monitoring. The priorities and monitoring plans are outlined in a Small Tributary Loading Strategy. Assessment of small tributary loading will continue to be a high priority topic for the Program, but the effort will move from intensive monitoring of a small number of watersheds to reconnaissance monitoring of a large number to identify watersheds where controls will be most beneficial. Another priority for the Program over the next few years will be to design and implement a plan to track the effectiveness of controls in reducing contaminant export to the Bay.

To address concerns about potential adverse nutrient impacts in the Bay, the Water Board worked collaboratively with stakeholders to develop the San Francisco Bay Nutrient Management Strategy

Nutrients

Nutrient pollution of the Bay was not even mentioned in the 2011 State of the Bay Report. Concern on this topic has risen rapidly over the last few years, however, driven primarily by observations of recent increases in the abundance of microscopic algae known as phytoplankton. Nutrient pollution has quickly become one of the top priorities of Bay water quality managers and scientists.

The Bay receives high nutrient loads from 40 wastewater treatment plants, agricultural runoff, and, to a lesser extent, stormwater. Nitrogen (N) and phosphorus (P) concentrations in much of the Bay are five to ten times higher than those in other estuaries that are impaired by nutrient pollution. However, the Bay has exhibited resistance to the classic symptoms of nutrient contamination that have plagued other nutrient-enriched estuaries, such as large algal blooms and low dissolved oxygen. High turbidity and strong tidal mixing in the Bay limit light levels and phytoplankton growth. Large populations of filter-feeding clams have further limited phytoplankton accumulation (Cloern and Jassby 2012).

Observations over the past 15 years have raised concerns that the Bay's resistance to its high nutrient loads has weakened, or that previously undiagnosed symptoms of nutrient overenrichment require further study. These include:

- a greater than 2-fold progressive increase in summer and fall phytoplankton biomass in South Bay from 1995 to 2005 (page 43);
- frequent detection of algal species that have been shown to form harmful algal blooms (HABs);
- frequent detection of the toxins microcystin and domoic acid that are produced by some harmful algae (page 47);
- low dissolved oxygen in some sloughs and tidal creeks (page 46); and
- studies suggesting that the form of nitrogen (ammonium versus nitrate) or ratio of nitrogen to phosphorus can affect the relative abundance of different kinds of phytoplankton and their growth rates.

To address concerns about potential adverse nutrient impacts in the Bay, the Water Board worked collaboratively with stakeholders to develop the San Francisco Bay Nutrient Management Strategy (SFBRWQCB 2012b). The Strategy lays out an overall approach for building the scientific understanding to support well-informed nutrient management decisions. Beginning in 2012, Bay Area municipalities and the RMP began to substantially increase funding for studies aimed at improving understanding of nutrients in the Bay.

Looking Ahead

Bay water quality managers and scientists have a busy agenda over the next few years, with plans in place for continued work to address emerging contaminants, legacy pollutants, and nutrients, as well as other pollutants including selenium (page 49), pathogens (page 56), and trash. The RMP will continue to track trends of these and many other pollutants through routine monitoring, to study the underlying processes so that management actions are well informed and successful, and to respond quickly to new information and the discovery of new concerns.

With the continued diligence of managers and scientists, Bay water quality will continue on a long-term path of gradual improvement with regard to reducing legacy pollution, and better recognition and action to curtail new pollutants before they make the Bay less safe for aquatic life, fishing, or swimming. ■

Sailing under the Golden Gate Bridge. Photograph by Phil Trowbridge.

San Francisco Bay in 50 Years: Warmer, Bigger, and Cleaner

by Ariel Rubissow-Okamoto
(ariel@bayariel.com)

HIGHLIGHTS

Six water quality experts were asked to speculate about Bay water quality in 50 years

It is expected that local sources of today's pollutants of concern will be under robust control and major pollution hotspots will have been cleaned up

Water flows and contaminant loads to the Bay from municipal wastewater and urban stormwater will be greatly reduced as these flows are increasingly conserved and used as a water supply

Climate change will cause important alterations in flows into the Bay, the spatial extent of the Bay and Bay habitat types, water movement, and water chemistry

New technologies will enhance monitoring of water quality, but the materials used for improvements in energy generation, transportation, and other sectors may include substances that pose new water quality threats

“In 50 years we’re going to have all pollutant sources of concern under robust control.”

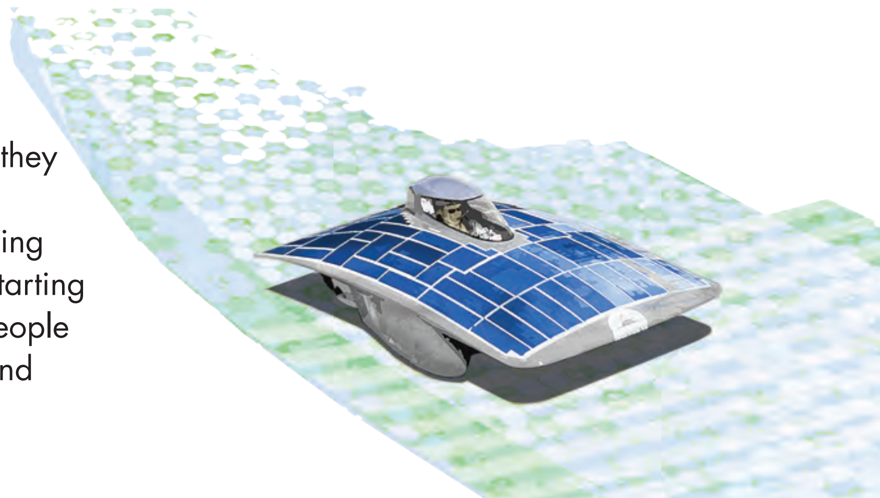
TOM MUMLEY

Six Experts Share Their Views

With a drought on their shoulders and sea level rise at their feet, the region’s leaders have been thinking hard about where to invest in upgrades to clean water facilities and coastal infrastructure. To explore some of the challenges that lie ahead, six leaders in various water quality fields were asked to speculate about how the Bay might look different in 50 years, and what might be the drivers of any change. Those interviewed have all been involved in water quality management or monitoring for many years: Adam Olivieri, Vice President of EOA, Inc.; David Sedlak, a professor at the University of California at Berkeley; Thomas Mumley, Assistant Executive Officer of the San Francisco Bay Regional Water Quality Control Board; Jay Davis, Lead Scientist for the RMP and Philip Trowbridge, its Manager; and James Ervin, Compliance Manager for the San Jose-Santa Clara Regional Wastewater Facility. Each represents a different perspective - ranging from regulator to discharger to researcher to academic - and years of experience working on Bay water quality.

“I don’t think the Bay’s problems will be better or worse in 2065, they will just be different,” says David Sedlak. “People have been working hard to protect the Bay and it’s starting to pay off. We’re seeing more people spending more time at the Bay and enjoying it.”

“In 50 years we’re going to have all pollutant sources of concern under robust control,” adds Tom Mumley. “Urban runoff will be very clean, after we’ve greened more concrete, and we’re already on the verge of making wastewater as clean as it can be.”



"In 2065 there will be no such thing as "waste" water. All water is valuable to us, and we will be reusing it one way or another..."

ADAM OLIVIERI

Down to a Trickle from Drains and Outfalls?

Impacts on the Bay from both wastewater discharges and urban runoff could change dramatically in 50 years, not only due to the billions of dollars in upgrades needed for aging infrastructure, pipes, outfalls, and treatment plants, but also due to changes in local environmental conditions. Experts predict prolonged drought, stronger storms, seasonal changes in precipitation, less snowmelt, and rising seas for Northern California, not to mention population growth, which will all change the amount of water flowing through our ecosystems. As fresh water becomes generally scarcer, water quality will be more linked than ever to water quantity.

Adam Olivieri thinks that in 2065 there will be no such thing as "waste" water. "All water is valuable to us, and we will be reusing it one way or another, either by recycling it onto the landscape or by treating it to a point where we can put it back in the drinking water supply. By then, treatment will be much more advanced and wastewater treatment plants might not be the source of emerging contaminants in the environment anymore."

Tom Mumley agrees: "In 50 years treated wastewater is going to be completely repurposed. We will no longer be discharging it into the Bay, as we do now, we're going to be reusing it for irrigation and habitat restoration."

Will this change the wastewater disposal landscape? Olivieri thinks so, though it won't functionally change water quality in the Bay or save us from drought, he says. "If we look at what we could recycle or replace in urban areas, it's smart but it's small in the statewide water supply picture."

Jim Ervin thinks far more benefits have come from water conservation than recycling to date: "The difference between dry season and wet season water use in urban areas tells us there's still a huge amount of landscape irrigation conservation that can be achieved."

Climate change and drought won't just affect how much water enters the Bay from treatment plant outfalls. It will also affect the amount and seasonal timing of snowmelt and freshwater outflows down Central Valley rivers and into the Bay. "Even if precipitation increases, or returns to normal, we'll still have less of it falling as snow and fewer of those big spring melts," says David Sedlak. "This will affect the way the Bay gets flushed in the springtime and how contaminants move through the Estuary. Right now they come through pretty quickly during the spring melt. In the future, when we're getting rain not snow in winter, flushing could be more episodic."

Contaminants also move into the Bay in urban stormwater runoff, as rain falls on roads, parking lots, and other impervious city surfaces laced with petroleum products, brake pad dust, pesticides, and the like. But a strong push right now to prevent these kinds of inputs from runoff may change this picture by 2065.

"We might need to think more about protecting Bay water quality if we're ultimately going to be drinking it."

DAVID SEDLAK

“I envision substantial conversion of the Bay Area greyscape into greenscape. This is not a dream, we’re essentially going to require it in a progressive way starting with the forthcoming permit.”

TOM MUMLEY

“I envision substantial conversion of the Bay Area greyscape into greenscape,” says Tom Mumley, who is in the midst of finalizing a regional stormwater discharge permit that will engage numerous municipalities in the task. “This is not a dream, we’re essentially going to require it in a progressive way starting with the forthcoming permit.”

Adds Sedlak: “Right now, whatever rain falls on our city landscapes flows out to the Bay pretty quickly, and often washes a lot of pollutants in with it. As we add more systems to either capture stormwater for reuse, or to filter it through green infrastructure, it could make the Bay cleaner.”

Olivieri had a slightly different take: “Practically speaking, I don’t think the big change is going to be green infrastructure and low impact development (LID), it’s going to be cities and water districts deciding they want to capture more water and use it for a higher purpose.”

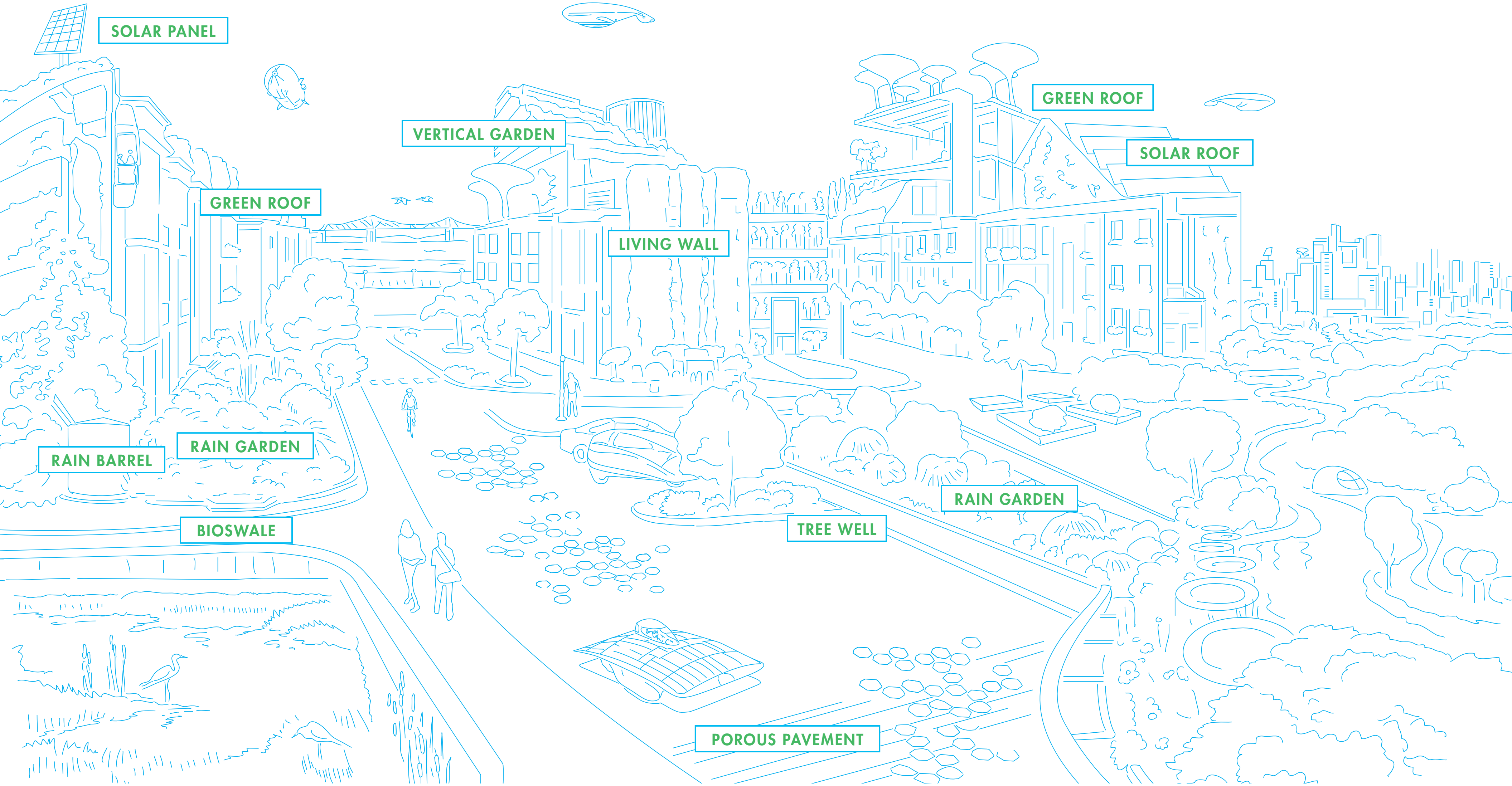
This kind of response to water shortages could also impact creeks, which are currently beginning to enjoy a renaissance as communities break them out of their concrete culverts and flood control districts rethink their role in flood management. “Once we combine in-stream and creek mouth habitat improvements with on-land green infrastructure, creeks can reclaim their role as vital arteries of life,” says Mumley.

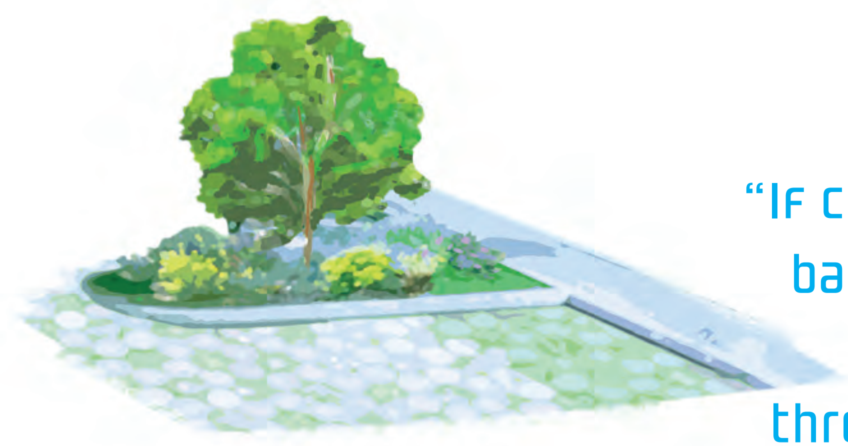
All these kinds of changes will also reduce the amount of fresh water that blends with the Bay at its margins, especially during the dry season. If warming leads to enhanced evaporation, and if there will be no wastewater discharge, some areas of the Bay, particularly in the South Bay, can be expected to become hyper-saline (saltier than the ocean). There is a precedent for this: South Bay became hyper-saline during the 1977 drought. Some species won’t be able to survive the new mix, while others may thrive.

Even then, however, portions of the Bay should continue to be less salty than the ocean, making it a possible source of drinking water in the future. “I can’t imagine that we wouldn’t be using desalination by 2065,” says Olivieri. “Then our water quality challenges will include how to dispose of brine and concentrated by-products from the treatment process, as well as the construction of new deep water outfalls for disposal.”

“We might need to think more about protecting Bay water quality if we’re ultimately going to be drinking it,” adds Sedlak. “Right now our assumption is that desalinated seawater is safe because it uses a membrane process to remove the salt which also removes everything else. But we may have to think more about toxic algal blooms, oil spills, and other threats to any desalination plant in the Bay.”

Vision of a Bay Area City in 2065





"If cities implement bag bans and Styrofoam bans effectively, we'll overcome resistance and begin to change consumer behavior through regulation and education. In 50 years, I'm hoping we'll have trained several generations of kids to change their own behavior, as well as to change their parents' behavior."

ADAM OLIVIERI

Lingering Legacies, More Invasives, Less Trash

More than two decades of monitoring, regulation, and cleanup collaboration has coalesced around a handful of high priority San Francisco Bay pollutants: PCBs, mercury, selenium, copper, polycyclic aromatic hydrocarbons (PAHs), trash, and invasive species. These pollutants were the subject of data collection and assessment by the RMP and other programs. Armed with good information, regulators crafted TMDLs and management strategies, and worked with municipalities, industry, and other contributors on curbing loads to the Bay. If these mandates continue to be carried out, things might look a little different in 2065.

For one, everyone seems certain there will be a lot less blowaway trash in our creeks, marshes, and bays than today. In the last five years, 69 cities bordering the more urbanized shores of the Bay and local creeks have participated in identifying trash generation hotspots, installing trash capture devices in storm drains, conducting creative public education programs, and passing various bans.

"If cities implement bag bans and Styrofoam bans effectively, we'll overcome resistance and begin to change consumer behavior through regulation and education," says Olivieri. "In 50 years, I'm hoping we'll have trained several generations of kids to change their own behavior, as well as to change their parents' behavior."

Trash is easier to collect and dispose of properly than "legacy" contaminants such as PCBs and mercury buried in the floor of the Bay. Under regional load targets and action plans laid out in TMDLs, industries and military sites have begun a process for cleaning up some of the hotspots that drain to the Bay. Despite these small initial successes and ambitious plans, legacy concerns are not going to go away anytime soon, according to Jay Davis. "One prediction I am confident about, unfortunately, is that mercury and PCB concentrations in Bay fish, while they will probably be lower than they are today, will still be problematic, primarily due to the reservoir that has already built up in Bay sediment."

For managers, the big difference between the two legacy challenges is that more mercury is being added every day from an uncontrolled source whereas the region has a good handle on remaining sources of PCBs. "Asia is projected to continue

"I am sure the years ahead will throw all kinds of curveballs at us. If ocean currents and water temperatures and freshwater flows keep changing, and if we keep bringing new organisms to the Bay on ships engaged in global trade, we could end up with an entirely different ecosystem."

DAVID SEDLAK

building more power plants and burning more coal for years to come, so emissions containing mercury are expected to rise and be transmitted globally to our waterways through the atmosphere," Davis explains.

One thing that is sure to change in 50 years, however, is the size and shape of the Bay where legacy contaminants lie sequestered. "Legacies get very effectively trapped in the Bay, and especially in its margins where there is not a lot of tidal action and flushing," says Davis. While major legacy hotspots should be cleaned up in 50 years, smaller pockets of these contaminants are likely to persist in the shoreline areas that will become submerged with sea level rise. Deposits of legacy contaminants in this shifting shoreline zone could be susceptible to mobilization due to sea level rise, king tides and extreme storm events, changes in patterns of erosion, or some combination thereof.

"Hopefully by 2065 we'll have cleaned up all the hot spots and be done with legacies, and we won't have created any new ones," says Olivieri.

We do keep adding new invasive species to the Bay, however, and they continue to impair the health of the ecosystem and beneficial uses of the Estuary. "Invasive species can really change water quality in the Bay – the Asian clam changed water clarity a great deal, for example, by filtering out so much of the plankton," says David Sedlak. "I am sure the years ahead will throw all kinds of curveballs like this at us. If ocean currents and water temperatures and freshwater flows keep changing, and if we keep bringing new organisms to the Bay on ships engaged in global trade, we could end up with an entirely different ecosystem. And the new system will cycle contaminants differently."

While experts agree on the need for continued vigilance, Tom Mumley argues that in 50 years, despite all the curveballs that may be thrown our way, we might have something to celebrate. "We may actually be at a point of realizing the ultimate goal of the Clean Water Act and National Pollutant Discharge & Elimination System – zero bad discharges," he says. "By 2065, we should be able to pretty much check off everything on the national priority pollutant list, and on our regional priority list, as either being of no concern, or as being well on the path to resolution, either through existing regulatory efforts or ones currently in the pipeline. It could be a profound point in Bay water quality history, and we could be seeing a Bay in recovery."

"We will continue to care about water quality in the Bay and it will continue to be a productive ecosystem. We'll want to track its condition and find better and better ways of doing so. With these tools, we can be less reactive and more pre-emptive."

JAY DAVIS

The Next and Last Big Things...

Looking at how today's water quality priorities may change tomorrow, a number of new things seem to be on the horizon. There's much talk of nutrients being the next big thing, and how to manage a Bay where there might be more unpleasant or toxic algae blooms.

"If we're thinking about what may change ecologically and hydrologically, we need to think about tipping points," says Davis. "We saw a tipping point for suspended sediment where the Bay suddenly became less turbid; we saw another with the invasion of the Asian clam, which radically changed the food web and selenium cycling. I'm concerned that we might see another tipping point when nutrient concentrations combine with other factors to increase phytoplankton and harmful algae blooms. Such shifts in an already perturbed system could result in dramatic impacts on uses of the Bay."

Other next big things we could be grappling with in 2065 might be contaminants from the groundswell of clean energy technologies, or the addition of more nanomaterials to natural ecosystems, with unforeseen results. "Hopefully the new chemicals and materials will all be green, non-persistent, and non-toxic, but it's another category of potential new pollutants to the Bay that may need to be on our future monitoring radar," says Davis.

One thing sure to be on the radar is ocean acidification, experts say, though no one is quite sure how the Bay, which will become increasingly influenced by the ocean, may be impacted. Bay pH levels swing widely, responding to both tides and plankton blooms, among other things, says Phil Trowbridge. Current pH sensors don't measure levels very accurately. Before investing in any new instruments to establish a more accurate baseline, Trowbridge wants to bring together ocean acidification and nutrient experts to develop a strong conceptual model of potential impacts. He wants to know which species, in which life stages, and which beneficial uses of the Bay, might be most vulnerable. "We don't have the data now to be saying much and we really wouldn't want to be in the same position in 2065," he says.

The latest really big thing we did to change Bay ecology was the restoration of thousands of acres of wetlands and transitional habitats, and another next big thing will be to nurture and grow this investment. These vast living sponges and shorelines promise to filter contaminants, trap sediments, and buffer us from storm events and sea level rise. By 2065, however, the rate of sea level rise will be accelerating and some of these hard-won marshes and mudflats could start to go under. "There'll be more water and less mudflat around the Bay," says Sedlak. If this is how the future unfolds, the capacity of these sponges for retention of contaminants and nutrients would be lost, and the stores accumulated in them could be released. An even bigger problem, however, would be that tidal marshes and intertidal habitats in general would disappear, and so would the species that depend on them.

But Jim Ervin remains skeptical that impacts will occur across the region. "Everybody talks about the mountain of water coming our way, and how the Bay is just going to be a giant lake, but nature seems to be keeping up pretty well in the South Bay, building marshes faster than the inundation rate," says Ervin. "If you review 150 years of data, and look through maps and aerial photos, anyone can see that every single channel got skinnier, that the marsh expanded, and that the salt ponds are filling up with sediment as soon as they are breached. So all this water is turning to land pretty fast."

These questions need to be answered soon. The fate of the Bay's intertidal habitats are hugely dependent on decisions that managers, planners, and voters will make in the next 15 years. Policy and permitting decisions that the Water Board, USEPA, and the US Army Corps of Engineers make relative to the Clean Water Act for sediment in creeks, in the Bay, and Bay fill are critical to these outcomes.

High Hopes and Better Information

Keeping its finger on the pulse of all these changes in the Bay and climate will require the Regional Monitoring Program to change too. Over time it's shifted focus from wastewater and deep water discharges to the shallows and margins, and in the future, it will likely shift again, this time from chemistry and contamination to biology and ecology. Trowbridge, the RMP manager, expects the Program to become more focused on ecological functions by 2065, and others agree.

"By 2065, we're going to have less need to chase chemicals and more need to understand how to keep the ecosystem healthy," says Tom Mumley. "We may have eliminated chemicals as a primary stressor and have shifted our focus to remaining stressors on the physical habitats and biology of the Bay."

Trowbridge and Davis talk about monitoring in 2065 being done by drones and remote sensors, and about new technologies that can measure many more constituents in the water more accurately. They also have high hopes for more advanced computer models that can better integrate environmental changes with complex water quality measurements.

"One thing I am sure about is that we will all continue to care about water quality in the Bay and it will continue to be a productive ecosystem, even if it's a different mix of species," says Davis. "So we'll want to track its condition and find better and better ways of doing that, probably with new sensors that can monitor conditions remotely and continuously. With these tools, we can be less reactive and more pre-emptive."

More data and better models will also help water quality managers and those in charge of our wastewater, stormwater, drinking water, and flood control infrastructure make more informed decisions and investments. "Recycling water is great, and green infrastructure is wonderful, and habitat restoration remains very important. But if we don't figure out how to reverse current trends in greenhouse gas emissions, and how to get not just the Bay Area but the whole planet pulling together, it's going to get ugly," says Sedlak.

> "My predecessor in the 1950s would have been bewildered, even stunned, to see what I see out my window today. There's no way in the world anyone would have put a wildlife education center and recreational trails right next to our facility in his day. By 2065, I expect to see not just flocks, but clouds, of geese and ducks every winter."
>
> JIM ERVIN

One way it could get ugly for water quality is something we might not have thought about yet, says Olivieri. "As things get hotter and the water level rises, and as freshwater lakes for recreation shrink, more and more people will want to go to the Bay and get in the water. Then the question becomes, is there anything in the water now, in terms of chemicals or pathogens, and that will be there in future, that people will be exposed to? We're probably talking about more gastro-intestinal problems and skin infections from more full body contact with the Bay." Such problems, however, are nothing new for many warmer estuaries, and many already have established solutions.

Asked to picture a dream estuary in 2065, nearly everyone interviewed said it would look "like it does today." Right now shorelines are being restored, many residents regularly visit the Bay for recreation, and the region, state and taxpayers remain committed to clean water, clean air, and a healthy ecosystem.

"My predecessor in the 50s would have been bewildered, even stunned, to see what I see out my window today," says Jim Ervin, recalling how putrid the discharge channels and sloughs next to his wastewater treatment plant were back then. "There's no way in the world anyone would have put a wildlife education center and recreational trails right next to our facility in his day. By 2065, much of the Bay will be an active wildlife refuge. I expect to see not just flocks, but clouds, of geese and ducks every winter."

"Our grandparents and great grandparents reinvented the modern world for us. To think that we can't do it for the next generation would be pretty pathetic," says David Sedlak.

"I like to think by 2065 we will have learned how to manage things better, so we'll still have beaches, still see green, and still see a beautiful Bay when we look out the window," says Olivieri. ■

> "Our grandparents and great grandparents reinvented the modern world for us. To think that we can't do it for the next generation would be pretty pathetic."
>
> DAVID SEDLAK

303(d) List

Section 303(d) of the 1972 Federal Clean Water Act requires that states develop a list of water bodies that do not meet water quality standards, establish priority rankings for waters on the list, and develop action plans, called Total Maximum Daily Loads (TMDLs), to improve water quality.

The list of impaired water bodies is revised every six years, with the next revision scheduled for 2016. The RMP is one of many entities that provide data to the State Water Board to compile the 303(d) List and to develop TMDLs. The process for developing the 303(d) List for the Bay includes the following steps:

- development of a draft list of recommendations by the San Francisco Bay Regional Water Board;
- adoption by the State Water Board; and
- approval by USEPA.

The primary pollutants/stressors for the Bay and its major tributaries on the 303(d) List include:

Trace elements: Mercury and Selenium

Pesticides: Dieldrin, Chlordane, and DDT

Other chlorinated compounds: PCBs, Dioxin and Furan Compounds

Others: Exotic Species, Trash, Polycyclic Aromatic Hydrocarbons (PAHs), and Pathogens

Damon Slough, Oakland. Photograph by Shira Bezalel.

Pollutants of Concern

POLLUTANT	STATUS
Copper	Site-specific objectives approved for entire Bay San Francisco Bay removed from 303(d) List in 2002
Dioxins / Furans	Updated assessment in 2017
Legacy Pesticides (Chlordane, Dieldrin, and DDT)	Monitoring recovery
Mercury	Bay TMDL and site-specific objectives approved in 2008 Guadalupe River Watershed TMDL approved in 2010
Pathogens	Richardson Bay TMDL adopted in 2008 Bay beaches (multiple listings); TMDL projected for completion in 2016
PCBs	TMDL approved in 2009
Selenium	North Bay TMDL projected for completion in 2015
Trash	Municipalities required to implement trash load controls in 2009

UPDATES ON PRIORITY CONTAMINANTS

RMP water sampling cruise. Photograph by Shira Bezalel.

Introduction

This edition of *The Pulse* provides a summary of Bay water quality in 2015, with an emphasis on how the Bay and our understanding of it have changed since the last assessment in 2011. The 2015 *Pulse* is a companion and supplement to the 2015 *State of the Estuary Report*, which includes a very concise summary of water quality in both the Bay and Delta.

RMP water sampling. Photograph by Shira Bezalel.

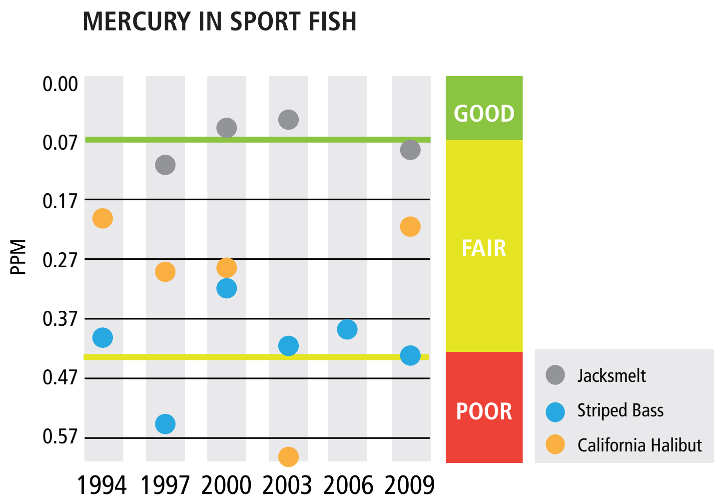
This section of *The Pulse* provides more detailed information on developments for the contaminants of greatest concern in the Bay. For each contaminant, recent advances in understanding the severity of the problem; spatial patterns; long-term trends; and sources, pathways, and loadings are described. Emphasis is placed on graphical summaries of the rich dataset generated by the RMP and other programs that makes the Bay one of the most thoroughly monitored estuaries in the world.

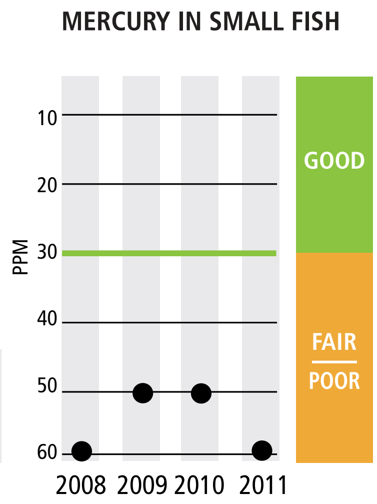
In 2002 the RMP adopted a spatially randomized sampling scheme for water and sediment in order to characterize spatial patterns and trends over time in a representative and unbiased manner. Now that this design has been in place for over 10 years, patterns and trends are emerging. Other long-term monitoring elements and focused short-term studies are also yielding valuable insights. The RMP and *The Pulse* will continue to track and report on these water quality stories as they unfold in years to come. ■

Mercury: Summary; Recent Advances

KEY POINTS

- Mercury contamination is a high priority for Bay water quality managers due to concern for risks to humans and wildlife
- A total maximum daily load (TMDL) control plan was approved in 2008
- Reduction of mercury inputs can be expected to slowly reduce mercury in the food web
- Minimizing conversion of mercury to methylmercury in salt ponds and restored marshes could potentially reduce local-scale food web mercury more quickly
- Preliminary results from monitoring tidal marsh restoration suggest that breaching salt ponds is not causing increases in food web mercury





Note inverted vertical axes. Bay-wide average concentrations. Data from the RMP. Graph details on page 61.

RECENT ADVANCES

The RMP published a review of the latest information on mercury in the Bay in 2012 (Davis et al. 2012), as part of a broader effort to summarize the state of knowledge of mercury cycling in coastal and marine ecosystems across the globe (Chen et al. 2012). Recent measurements of mercury accumulation in sport fish indicate that human exposure from fish consumption is a continuing concern (page 34). Ackerman et al. (2014) summarized extensive studies of mercury accumulation and risks in Bay birds, which face high risks of impaired reproduction based on mercury concentrations in the tissues of several species.

Studies indicate that the large pool of mercury already present in Bay sediment is the dominant supply that is converted to methylmercury (the toxic form of mercury), which is then accumulated in the food web. Consequently, it will likely take many decades before reduced loads of mercury to the Bay result in lower mercury in the food web.

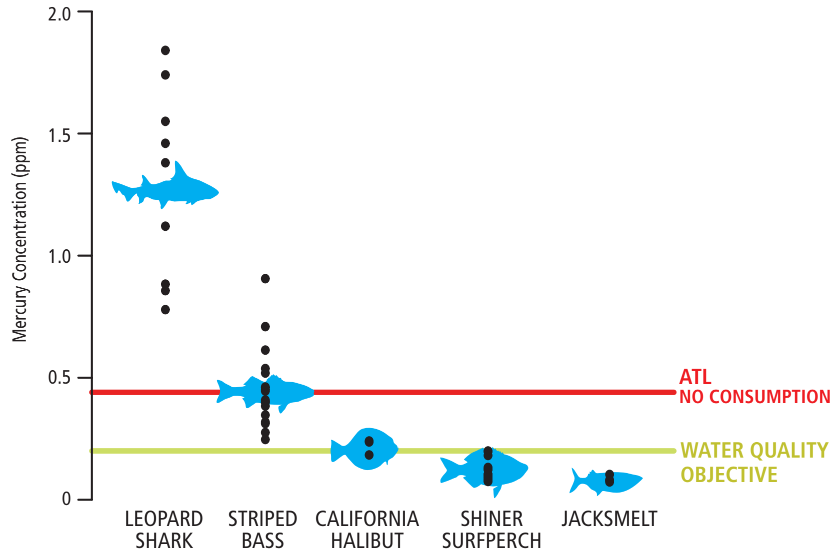
Controlling conversion of mercury to methylmercury is the second important management approach, and has the potential to reduce food web mercury within a much shorter time-frame. Options for controlling methylmercury production in the open Bay are limited, but do appear feasible in tidal marsh restoration projects and salt ponds, which are important habitats for at-risk bird species.

The RMP sponsored a forum in 2013 to review available information and data gaps relating to managing mercury in restored tidal marshes in the Bay. There was support for a regional approach to monitoring, with some sites selected for detailed investigation. Continued pilot studies and research may identify design features for some sites that minimize mercury in the food web.

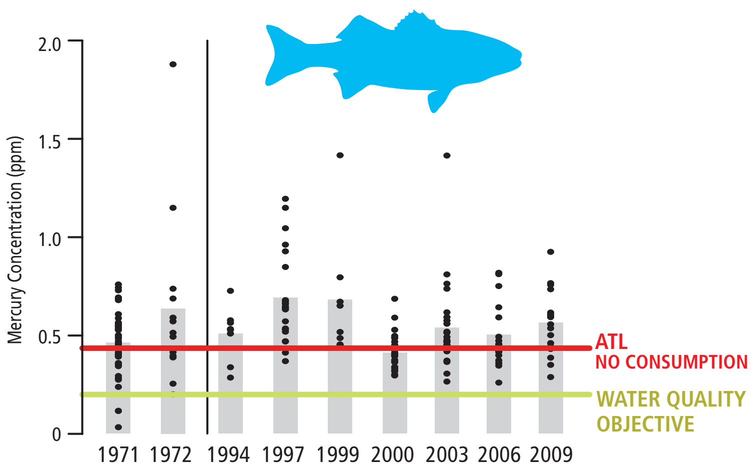
Findings to date from monitoring of marsh restoration projects in the North Bay (page 36) and South Bay indicate that opening ponds to tidal action is not leading to increases in food web mercury. Continued monitoring is needed to determine whether this can be considered a general pattern.

Mercury: Impairment

Striped bass from the Bay have the highest average mercury concentration measured for this species in US estuaries, and this degree of contamination has been constant for the past 40 years. Concern for human exposure to mercury has contributed to the need for an advisory for consumption of Bay sport fish.



Mercury concentrations (ppm) in sport fish species in San Francisco Bay, 2009. Fish icons indicate average concentrations. Points represent individual samples (either composites or individual fish). Data from the RMP. Additional details on page 61.



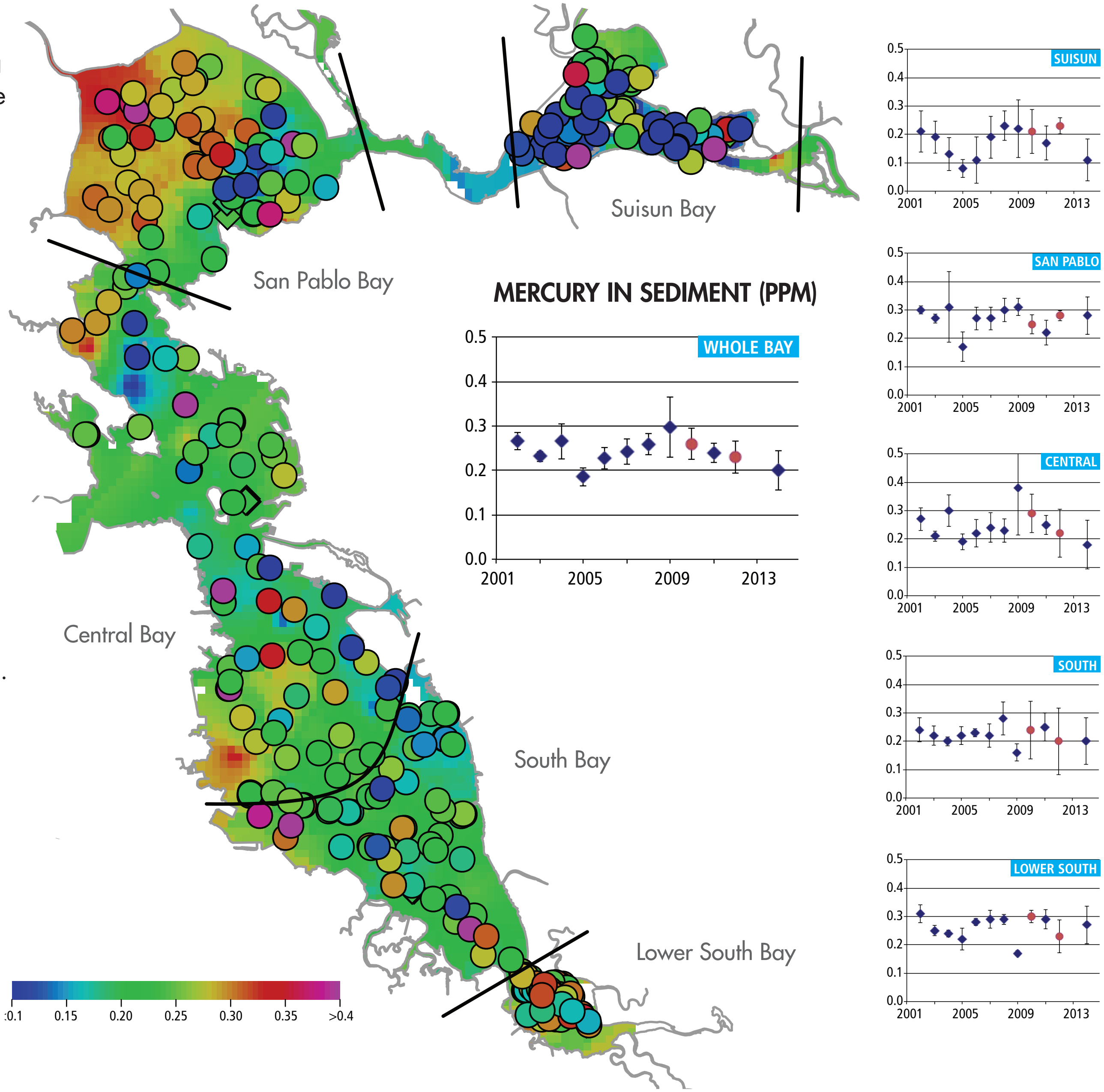
Mercury concentrations (ppm) in striped bass from San Francisco Bay, 1971-2009. Bars indicate average concentrations. Points represent individual fish. Data from the RMP (1994-2009) and an earlier study (1971-1972). Additional details on page 61.

In 2011 the California Office of Environmental Health Hazard Assessment (OEHHA) used RMP data collected between 1997 and 2009 to develop an updated and more comprehensive fish consumption advisory for the Bay. The advisory includes new species – Chinook salmon, jacksmelt, brown rockfish, and red rock crab – all of which had relatively low mercury levels. Only shark species exceeded OEHHA's advisory threshold for no consumption (0.44 ppm), although striped bass were close to this level. The advisory allows at least one eight ounce serving per week of all other species by women between the ages of 18 and 45 and children aged 1–17.

Mercury: Spatial and Temporal Patterns

Mercury concentrations in Bay sediment do not appear to be increasing or decreasing. The Baywide average concentration in 2014 (0.20 ppm) was the second lowest over the 12 rounds of sampling, but this was largely driven by some very low values in Central Bay. The time series within the segments do not suggest trends.

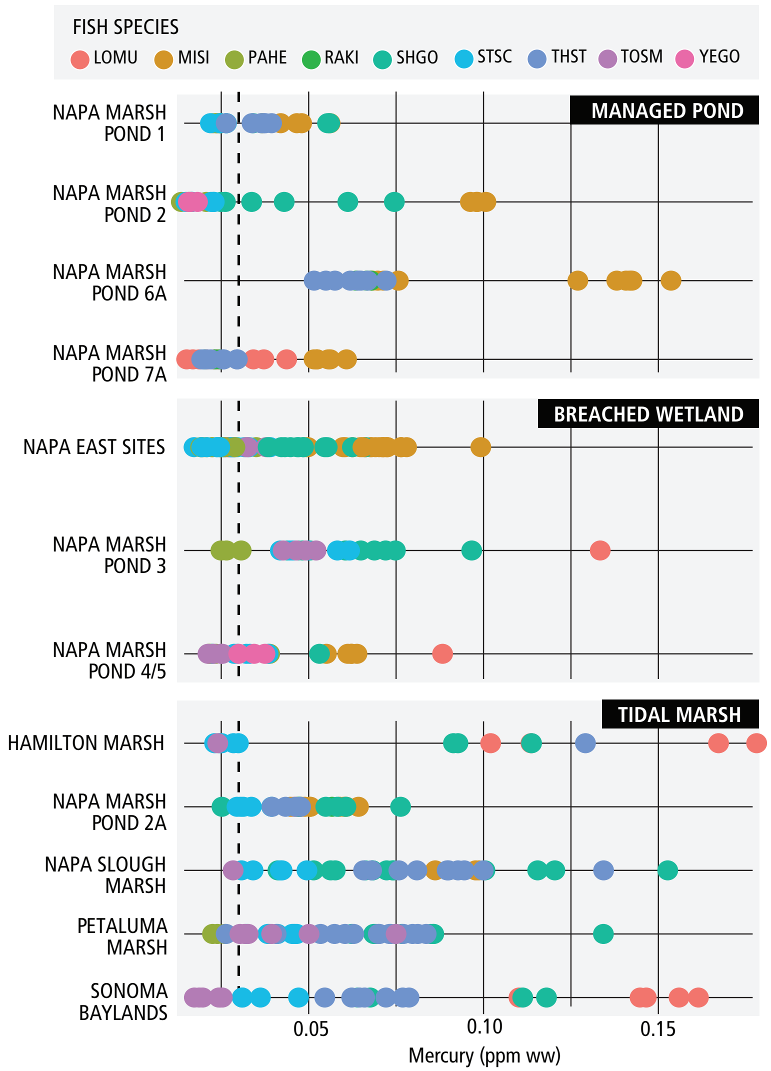
Average mercury concentrations in sediment have been highest in San Pablo Bay (0.27 ppm). Average concentrations have been slightly lower in Lower South Bay (0.26 ppm), Central Bay (0.25 ppm), and South Bay (0.22 ppm), and lowest in Suisun Bay (0.17 ppm). The Baywide average for the 10 rounds of dry season sampling was 0.24 ppm.



Contours and points on the map show all available dry season RMP data from 2002-2014. Trend plots show annual random-station means with error bars indicating the 95% confidence intervals of the means. Red circles on trend plots indicate wet season samples; other samples were dry season. Additional details on page 61.

Mercury: Sources, Pathways, and Loadings; Next Steps

FISH MERCURY IN NORTH BAY WETLANDS



Mercury concentrations for multiple fish species by site. Dashed line = 0.03 ppm water quality objective. Data from Robinson et al. (2014). Additional details on page 61.

MERCURY LOADS TO THE BAY (kg/year)

PATHWAY	TMDL ALLOCATION	TMDL LOAD ESTIMATE	LATEST LOAD ESTIMATE	COMMENTS
POTWs	20	20	2.9	SFBRWQCB (2012)
Industry			0.4	SFBRWQCB (2012)
Urban Stormwater	82	160	120	McKee et al. (2015)
Central Valley	330	440	190	David et al. (2015)
Atmospheric Deposition	7	27.2	–	New estimate not available
Bed Erosion	220	460	–	New estimate not available
Guadalupe River	2	92	90	McKee et al. (2015)
Non-urban Stormwater	25	25	–	New estimate not available
Sediment Dredging and Disposal	0	Net loss	–	New estimate not available

POTW - Publicly owned treatment works

▲

Mercury load reduction efforts are primarily focusing on the Guadalupe River and urban stormwater. Extensive efforts to reduce loads to the Bay via the Guadalupe River from the largest mercury mining source (the historic New Almaden mining district) have been underway for over a decade and are planned to continue for at least another two decades. Mercury is spread widely across the urban landscape, but there are a number of key sources, source areas, and pathways that provide opportunities to capture larger quantities and reduce loads from urban stormwater. RMP studies to support management of urban stormwater currently focus on identifying watersheds that are exporting highly contaminated sediment particles, developing improved estimates of loads at a regional scale, developing an approach to tracking long-term trends in loads, and predicting the effectiveness of management actions in reducing loads.

◀

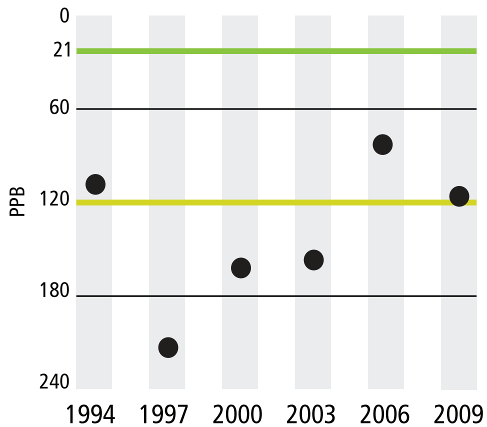
Concerns that tidal marsh restoration could exacerbate the Bay's mercury problem appear to be diminishing. Recent monitoring of marsh restoration projects in the North Bay and South Bay indicates that opening ponds to tidal action is not leading to increases in food web mercury. For example, fish monitoring in the Napa River region in 2012 and 2013 found that mercury concentrations in breached wetlands were not elevated relative to managed ponds and established tidal marshes. While breached wetlands may not pose a particular problem, there is still cause for concern across all of these habitats as concentrations in fish are usually above the water quality objective for protection of fish-eating birds.

PCBs: Summary; Recent Advances

KEY POINTS

- PCB contamination is a high priority for Bay water quality managers due to concerns for risks to humans and wildlife
- A TMDL was approved in 2009
- Monitoring of small fish along the margins of the Bay in 2010 showed higher and more persistent PCB concentrations than in the open Bay
- An updated conceptual model calls for monitoring and management to focus on contaminated areas on the Bay margins

PCBS IN SPORT FISH



Note inverted vertical axis. Bay-wide average concentrations. Data from the RMP. Graph details on page 61.

Shiner surfperch. Photograph by Jim Ervin.

RECENT ADVANCES

In 2014 the RMP completed a report (Davis et al. 2014) summarizing advances in understanding of PCBs in the Bay since the data synthesis for the PCBs TMDL (SFBRWQCB 2008).

New information obtained from RMP monitoring of small fish along the margins of the Bay in 2010 solidified our understanding of PCB contamination of the Bay food web and potential pathways of exposure for sensitive wildlife species such as birds and seals.

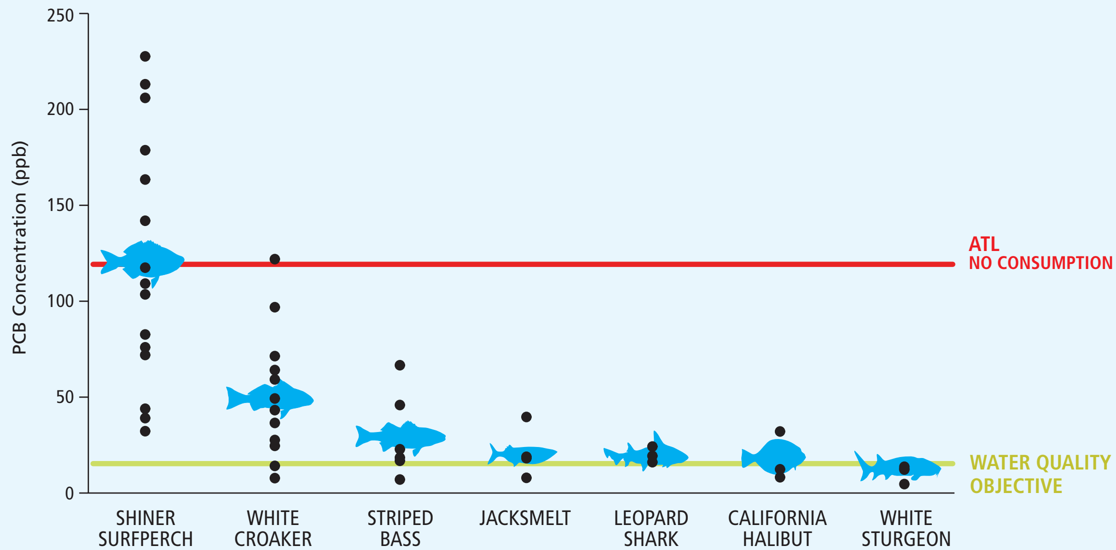
The data on PCBs in fish and sediment indicate that there are two broad habitat categories with food webs that are largely distinct: the margins and the open Bay. PCB concentrations in many areas on the margins are very high and persistent.

The report presented a conceptual model update that focused attention on contaminated areas on the Bay margins where impairment is greatest, where load reductions are being pursued, and where improvement in response to load reductions would be most apparent. The report concluded that these margin areas should be treated as discrete local-scale units for monitoring, forecasting, and management. Local-scale actions in upstream watersheds or in the margin areas themselves will be needed to reduce contamination within that area.

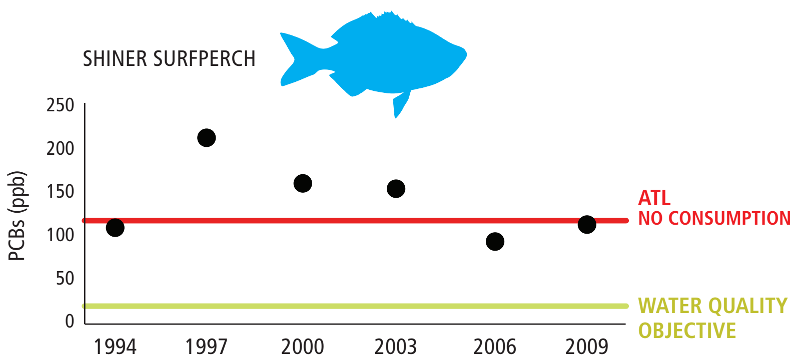
PCB inputs to the Bay from local watersheds are significant and a focus of management attention. Several watersheds have been identified as “high leverage” because they have the highest known concentrations of PCBs and may present good opportunities for load reduction. Stormwater management agencies are currently evaluating actions to address the PCBs TMDL load reduction requirements. RMP studies over the next several years are being designed to identify where management actions may be most effective and to track their effectiveness in reducing concentrations in the Bay.

PCBs: Impairment

Concern for PCBs in the Bay is primarily due to concentrations in sport fish. Shiner surfperch have the highest concentrations - 12 times higher than the water quality objective. Because of the high concentrations in shiner surfperch, the Office of Environmental Health Hazard Assessment advises no consumption of any surfperch species in the Bay. All other sport fish species monitored also have average concentrations exceeding the water quality objective. There is also evidence of PCB exposure in birds, seals, and fish to a degree that may be reducing their health and survival.



PCB concentrations (ppb) in sport fish species in San Francisco Bay, 2009. Fish icons indicate average concentrations. Points represent values for each composite sample. Data from the RMP. Additional details on page 61.



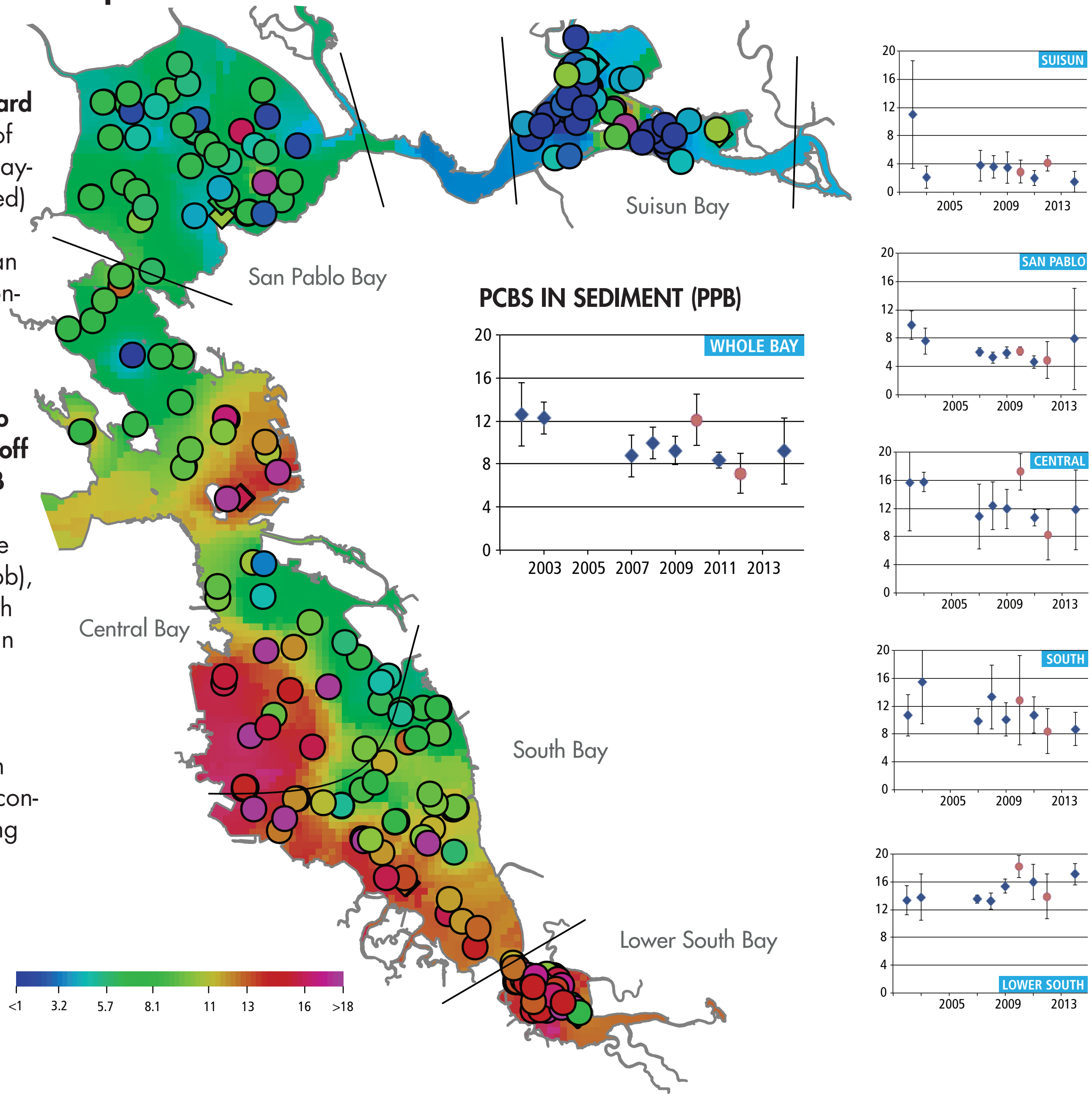
Bay-wide average PCB concentrations. Data from the RMP and Fairey et al. (1997). Additional details on page 61.

PCB concentrations in shiner surfperch, a key indicator species in the TMDL, have shown little evidence of decline. The Bay-wide average shiner surfperch concentration was lower in 2009 than in 1997, but not significantly different from 2000, 2003, or 2006 (left). Furthermore, the variation seen over the six rounds of sampling was primarily due to variation in the fat content of the fish, and not due to declines in PCBs in the food web.

PCBs: Spatial and Temporal Patterns

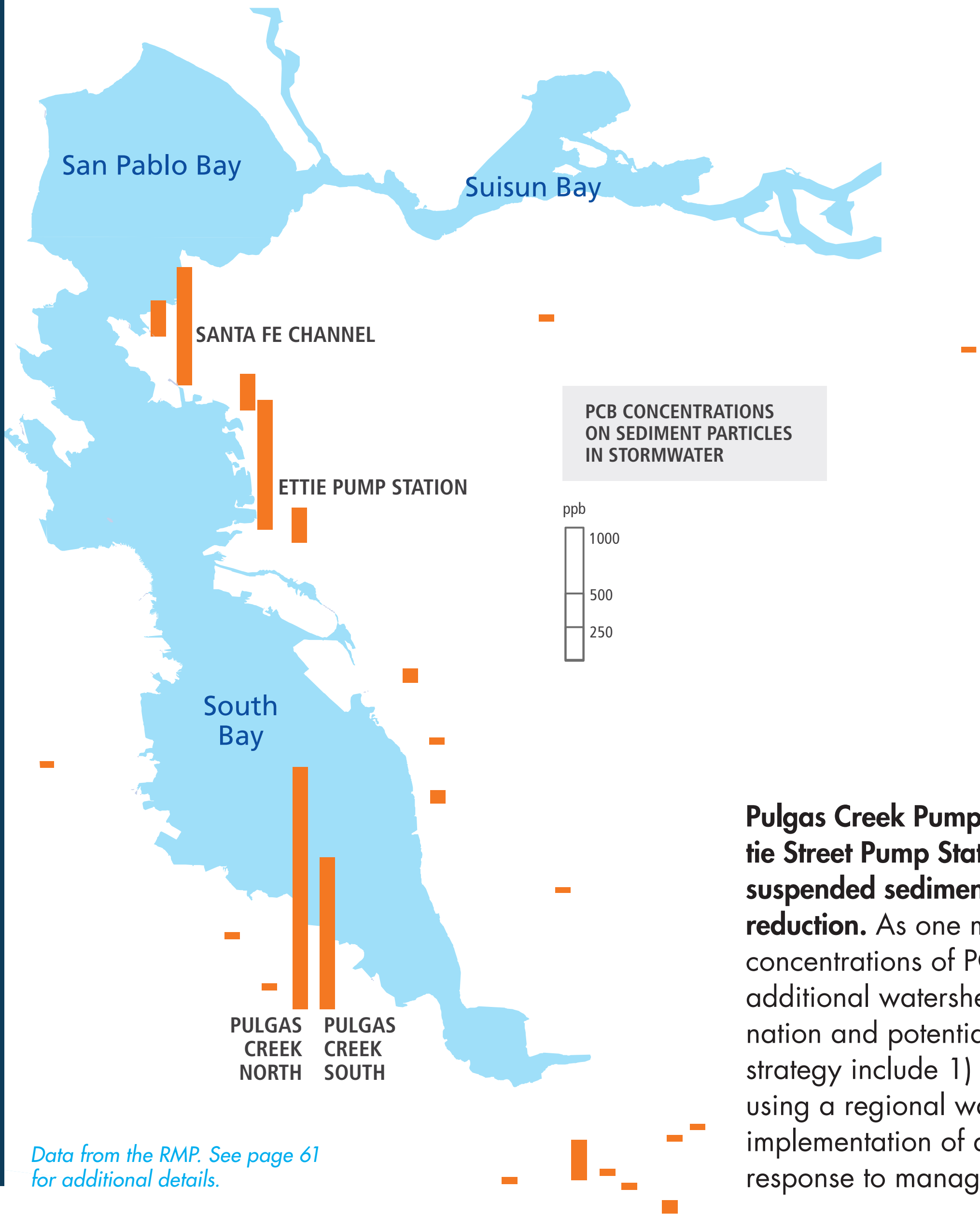
PCB concentrations in Bay sediment appear to be trending downward in Central Bay and South Bay, but upward in Lower South Bay. The large area of Central and South bays causes the Bay-wide average (which is area-weighted) to also appear to be on the decline. Concentrations in Suisun Bay and San Pablo Bay appear to be relatively constant over time.

PCB concentrations are higher in the southern arm of the Bay, likely due to historic and ongoing stormwater runoff from industrial areas and legacy PCB cleanup sites, such as military facilities, in this region. Long-term average concentrations in Central Bay (13 ppb), South Bay (12 ppb), and Lower South Bay (14 ppb) are higher than those in San Pablo Bay (6.3 ppb) and Suisun Bay (4.2 ppb). In 2014, Suisun Bay had its lowest average concentration yet observed (1.5 ppb), as did South Bay (8.7 ppb). Many of the highest concentrations have been observed along the shoreline of southwestern Central Bay and western South Bay.



Contours and points on the map show all available RMP dry season data from 2002-2014. Trend plots show annual random-station means with error bars indicating the 95% confidence intervals of the means. Red circles on trend plots indicate wet season samples; other samples were dry season. Additional details on page 61.

PCBs: Sources, Pathways, and Loadings



Data from the RMP. See page 61 for additional details.

PCB LOADS TO THE BAY (kg/year)

PATHWAY	TMDL ALLOCATION	TMDL LOAD ESTIMATE	LATEST LOAD ESTIMATE	COMMENTS
POTWs	2	2.3	0.95	SFBRWQCB (2012)
Industry	0.035	0.035	0.007	SFBRWQCB (2012)
Stormwater	2	20	19	McKee et al. (2015)
Central Valley	5	11	7.9	David et al. (2015)
Atmospheric Deposition	0	Net Loss	Net Loss	

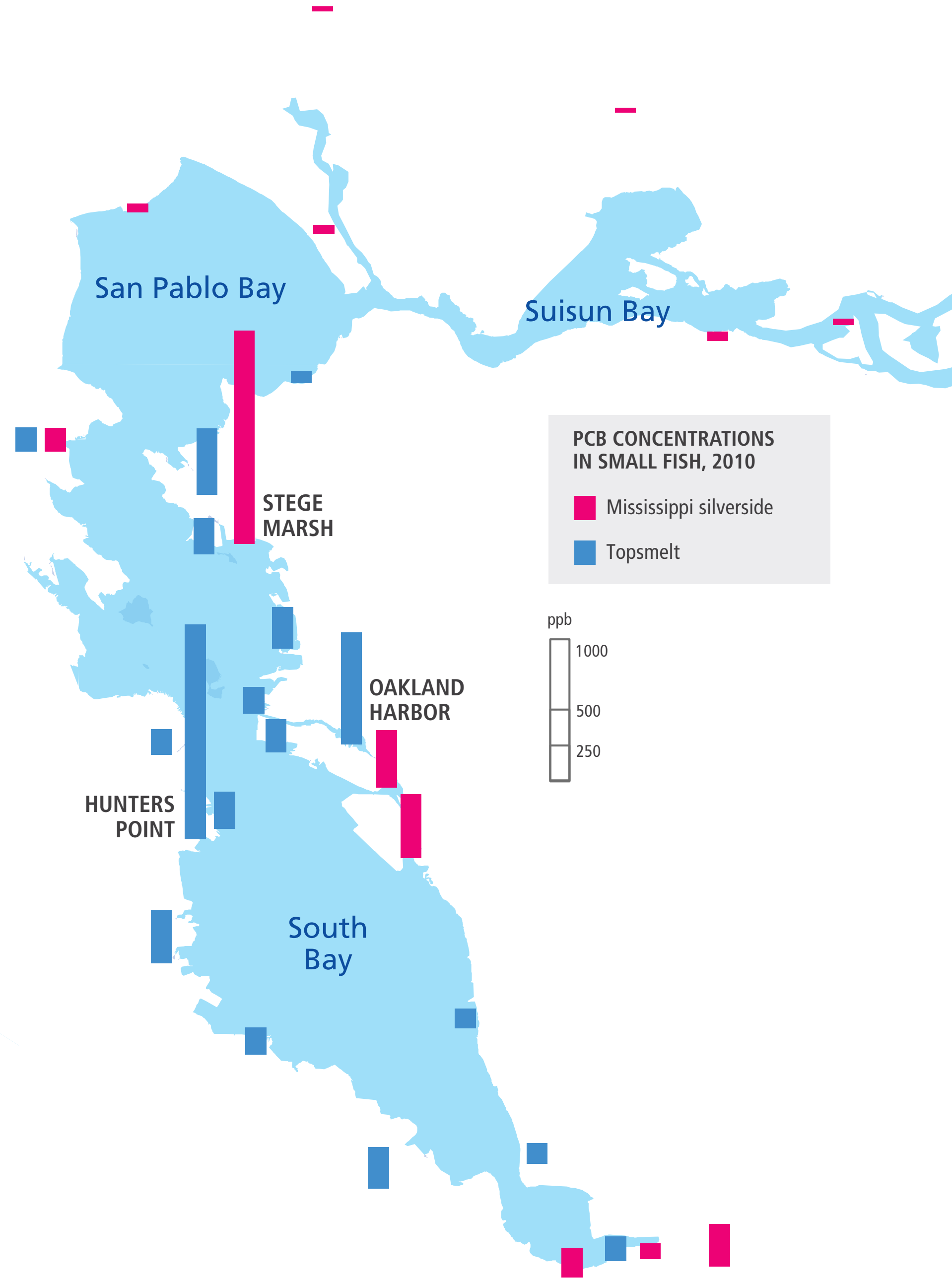
Urban stormwater remains the largest pathway of PCB loads to the Bay. The latest estimate of the load from urban stormwater is 19 kg per year, essentially the same as the estimate from the TMDL staff report in 2008. An updated estimate of loads to the Bay from the Delta was slightly lower than the estimate included in the PCBs TMDL. Recent estimates of total loads for POTWs and industrial facilities were well below the load allocations in the TMDL.

Pulgas Creek Pump Station North and South, Santa Fe Channel, and Ettie Street Pump Station have the highest known concentrations of PCBs on suspended sediment particles and may present good opportunities for load reduction. As one major element of the RMP Small Tributary Loading Strategy, concentrations of PCBs and mercury on suspended sediment particles from additional watersheds are being measured as an index of degree of contamination and potential for effective management action. Other elements of the strategy include 1) continued refinement of estimates of total regional loads using a regional watershed spreadsheet model, and 2) development and implementation of a plan to monitor reductions in small tributary loading in response to management actions.

PCBs: Important New Findings

RMP monitoring of small fish along the margins of the Bay in 2010 enhanced our understanding of PCB contamination of the Bay food web and potential pathways of exposure for sensitive wildlife species such as birds and seals. Small fish collected on the Bay margins accumulate high concentrations of PCBs that correlate with concentrations in sediment and represent a pathway for impact on fish-eating wildlife. These data, along with data for shiner surfperch, point to several contaminated margin areas that are high priorities for management.

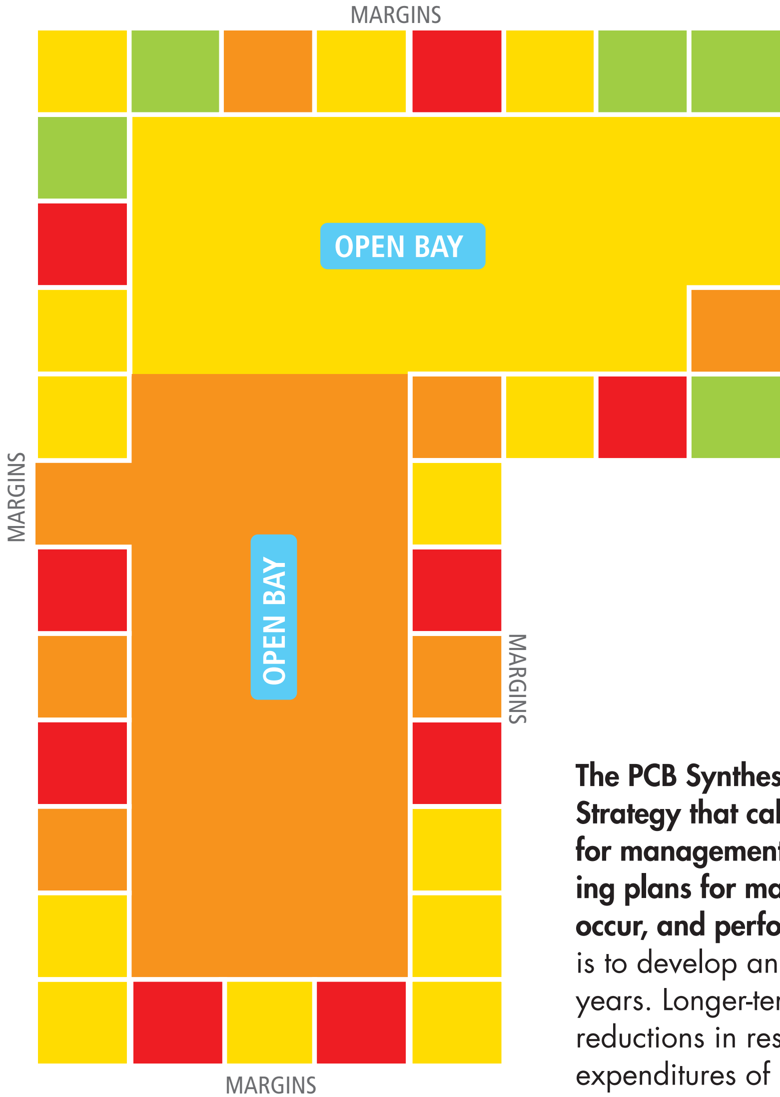
Recent studies identified PCB 11, a PCB that had been previously overlooked, as an ubiquitous contaminant owing to its widespread use in pigments in paint and ink in newspapers, magazines, and cardboard boxes. Based on the RMP data, PCB 11 that enters the Bay in wastewater and urban runoff is not persistent and is not accumulating in the food web. PCB 11 is a major PCB component in Bay water (3.7%, 6th most abundant congener) and urban runoff (2.8%, 8th), but is only 31st in Bay sediment (0.9%), and not in the top 40 in small fish or bivalves. PCB 11 should be considered separately from the Aroclor-derived PCBs that present risks to humans and wildlife.

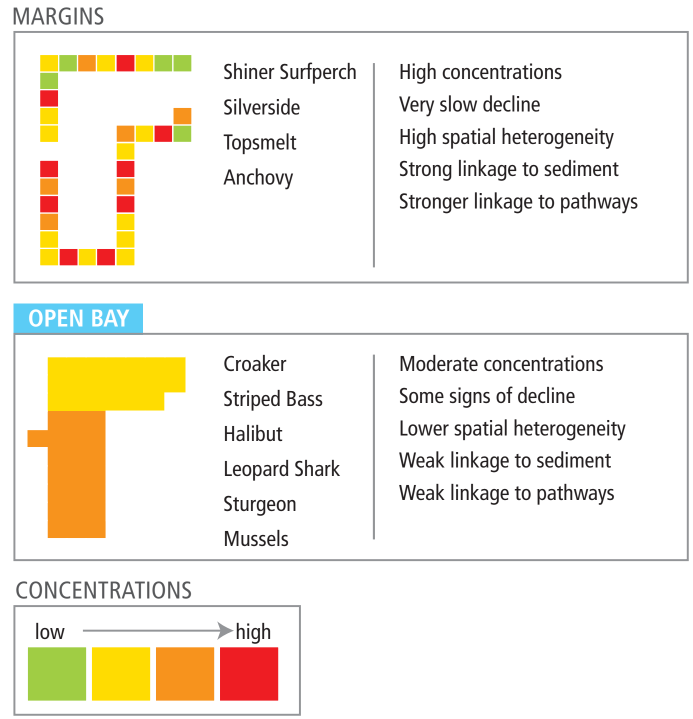


Data from the RMP. See page 61 for additional details.

PCBs: Next Steps

SCHEMATIC OF THE CONCEPTUAL MODEL FOR PCBS IN THE BAY





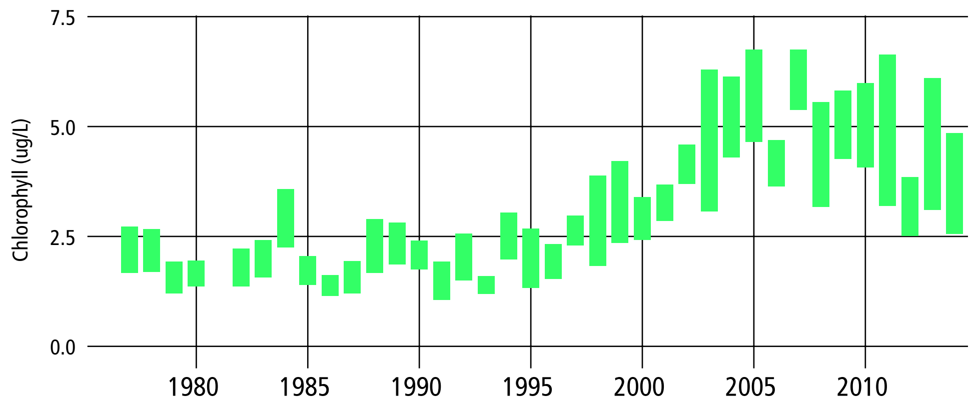
The PCB Synthesis (Davis et al. 2014) was the foundation for a 2014 update of the PCB Strategy that calls for a multi-year effort to identify margin areas that are high priorities for management and monitoring, develop site-specific assessments and optimized monitoring plans for margin areas downstream of watersheds where management actions will occur, and perform monitoring in these areas as a performance measure. The current plan is to develop and initiate monitoring for several priority margin areas over the next five years. Longer-term monitoring of these areas would then continue in order to detect PCB reductions in response to the actions taken. A thoughtful effort is warranted given the large expenditures of resources that will be needed to implement management actions to reduce PCB loads from urban stormwater.

Nutrients: Summary; Recent Advances

KEY POINTS

- Nitrogen (N) and phosphorus (P) concentrations in the Bay substantially exceed those in other estuaries where water quality has been impaired by nutrient pollution
- To date, the Bay has exhibited resistance to the problems that have plagued other nutrient-enriched estuaries, such as large algal blooms and low dissolved oxygen
- Observations over the past 15 years suggest that the Bay's resistance to its high nutrient loads is weakening
- Late summer chlorophyll in the South Bay increased from roughly 1995 to 2005 but has since leveled off
- Nitrogen loads and concentrations vary considerably by Bay segment and by season
- Nitrogen concentrations have shown long-term declines in Lower South Bay, and long-term increases in Suisun Bay
- Dissolved oxygen levels are generally above the water quality objective of 5 mg/L in the open Bay, but frequently below it in some sloughs on the Bay margins
- Algal toxins are commonly detected at low to moderate concentrations year-round throughout the Bay
- To address concerns about potential adverse impacts of nutrients, the Water Board and stakeholders developed the San Francisco Bay Nutrient Management Strategy in 2012

LATE SUMMER CHLOROPHYLL IN THE SOUTH BAY



The middle range (between the 25th and 75th percentiles) of annual chlorophyll concentrations in the South Bay in late summer. Historically, the South Bay had low chlorophyll production compared to other estuaries with comparable nutrient inputs. Data from USGS. Additional details on page 61.

RECENT ADVANCES

A Bay-wide nutrient discharge permit for municipal wastewater dischargers went into effect in July 2014, which sets aside funding to support science and monitoring to inform nutrient management decisions.

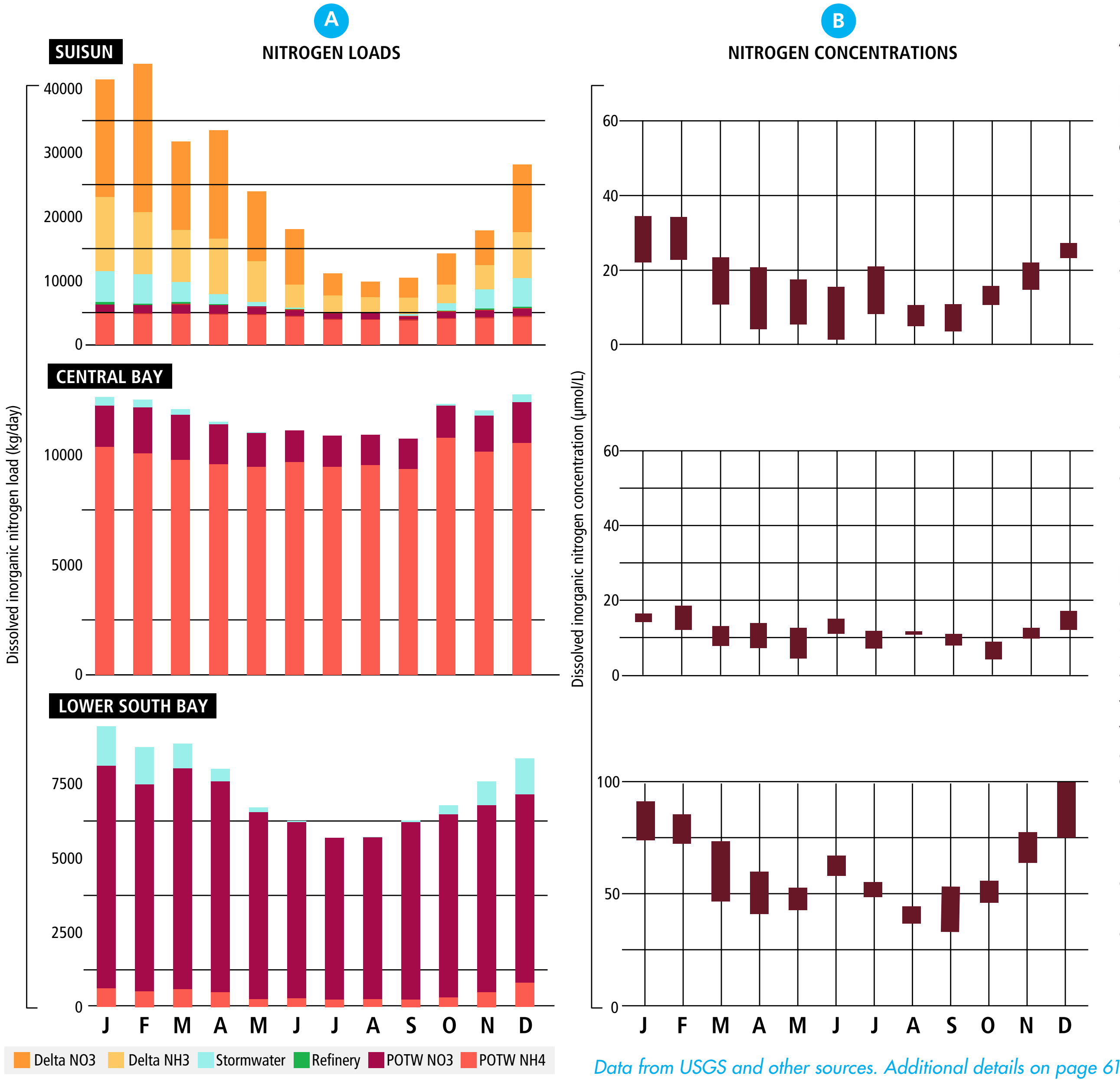
A multi-stakeholder Steering Committee was formed in April 2014 to guide implementation of the Bay Nutrient Management Strategy.

A network of moored sensors for measuring water quality parameters such as chlorophyll and dissolved oxygen has been initiated.

Method development and monitoring program design are underway for harmful algae, algal toxins, and more efficiently characterizing phytoplankton community composition.

More information, reports, and updates are available at: www.sfbaynutrients.sfei.org

Nutrients: Loads and Concentrations



Data from USGS and other sources. Additional details on page 61.

A

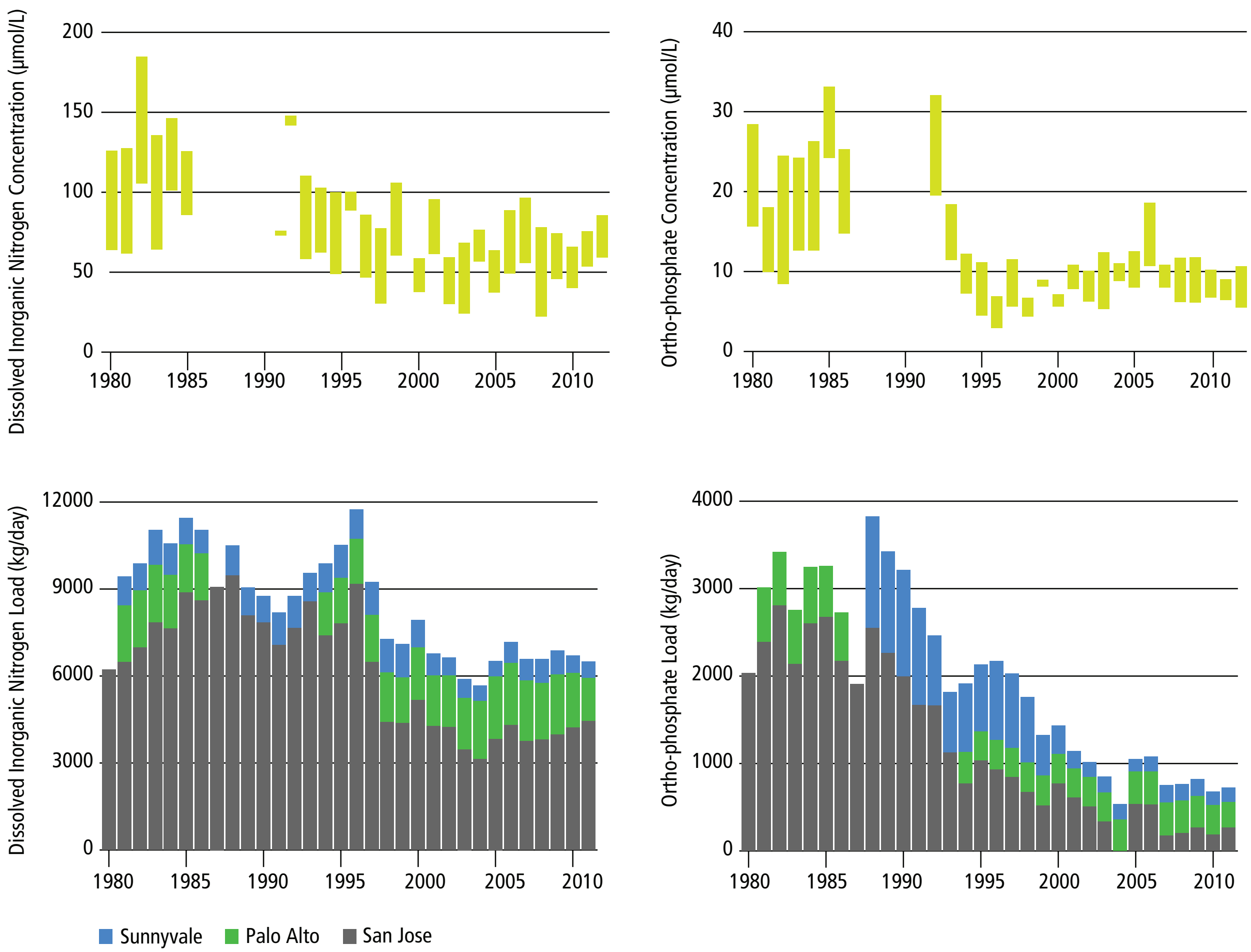
Nitrogen (N) loads differ substantially by subembayment – in terms of their magnitude, major source, seasonality, and form of N (ammonium vs. nitrate). Delta loads dominate in Suisun Bay in all seasons but mid-summer. Direct inputs to Central Bay come primarily from POTWs; however Central Bay also receives inputs through exchange with other subembayments. The coastal ocean can also be a source of nutrients to Central Bay during strong upwelling periods. POTW loads dominate in Lower South Bay. POTWs in Lower South Bay nitrify wastewater and therefore discharge mainly nitrate, but most other POTWs in the Bay Area discharge mainly ammonium.

B

N concentrations also vary by subembayment. Concentrations tend to be highest in Lower South Bay, but both Lower South Bay and Suisun Bay show strong seasonality. Central Bay tends to have the lowest N concentrations. Some of this variability is due to seasonal and spatial variability in loading. The variability is also caused by physical and biogeochemical processes. Once ammonium and nitrate enter the Bay, they are transported by strong tidal currents and wind-driven mixing, mixed and diluted within very different water volumes, and undergo numerous transformations (e.g., nitrification, denitrification, assimilation).

Nutrients: Loads and Concentrations

NITROGEN AND PHOSPHORUS IN LOWER SOUTH BAY



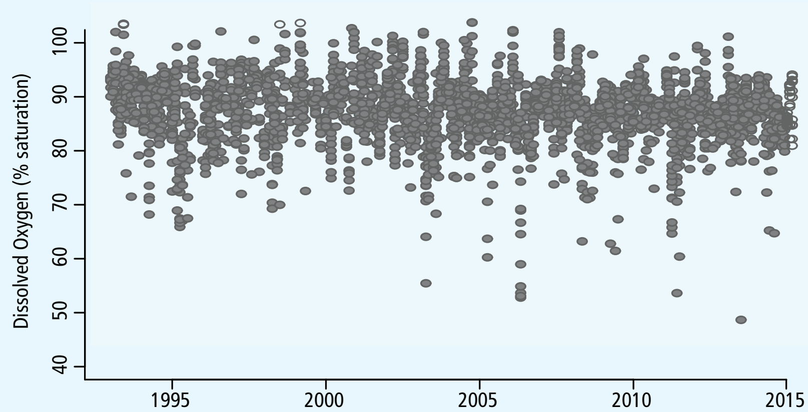
Nitrogen (N) and phosphorus (P) concentrations have decreased substantially in Lower South Bay over the past 20 years (top graphs). N concentrations have decreased by 40% due primarily to upgrades in San Jose's wastewater treatment process (bottom left). P concentrations have decreased by more than 50% due to a combination of San Jose treatment optimization and the phase out of phosphate in detergents (bottom right).

Nutrient concentrations have not shown similar decreases in other parts of the Bay. For example, in Suisun Bay, N concentrations have increased substantially in the last several decades, while P concentrations are similar to values measured in the 1970s and 1980s. Fewer historic load data are available for Suisun Bay, making it more difficult to determine what is driving these changes in concentration.

Top graphs show the middle range (between the 25th and 75th percentiles) for each year. Data from USGS and other sources. Additional details on page 61.

Nutrients: Dissolved Oxygen

Dissolved oxygen (DO) concentration is an important indicator of estuarine habitat condition because fish and sediment-dwelling organisms require some minimum DO level to prosper. Low DO is a common aquatic ecosystem response to elevated organic matter inputs, including organic matter produced in the ecosystem as a result of high nutrient concentrations. Low DO can also occur periodically in unimpacted systems. Discrete biweekly or monthly samples from the main channel of South Bay indicate that DO levels are generally above the Basin Plan standard (either 80% saturation or 5 mg/L).

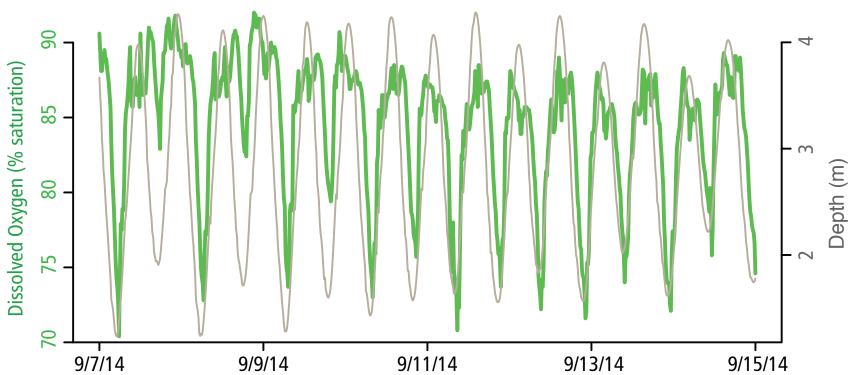


Data from the main channel of South Bay. Discrete samples collected 1-2 times per month by USGS. Additional details on page 61.

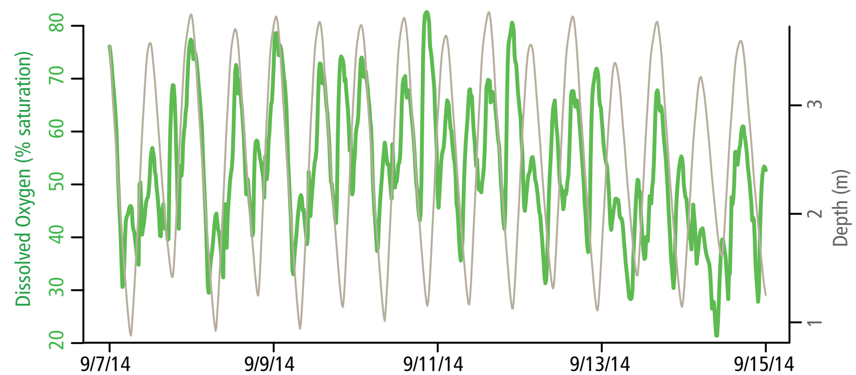
Recent high-frequency data from South Bay (Dumbarton Bridge) and a slough site in Lower South Bay (Alviso Slough) show that there can be substantial variability that is not captured by biweekly or monthly sampling.

- At Dumbarton Bridge, DO can vary by roughly 20% between high and low tide.
- Conditions are more variable at Alviso Slough, where DO can vary 60% over a tidal cycle.
- Relatively low DO can persist for several hours in Alviso Slough.
- Chlorophyll (not shown) also varies tidally at these two sites, and is 5-10 times higher in Alviso Slough than at the Dumbarton Bridge.

DUMBARTON BRIDGE



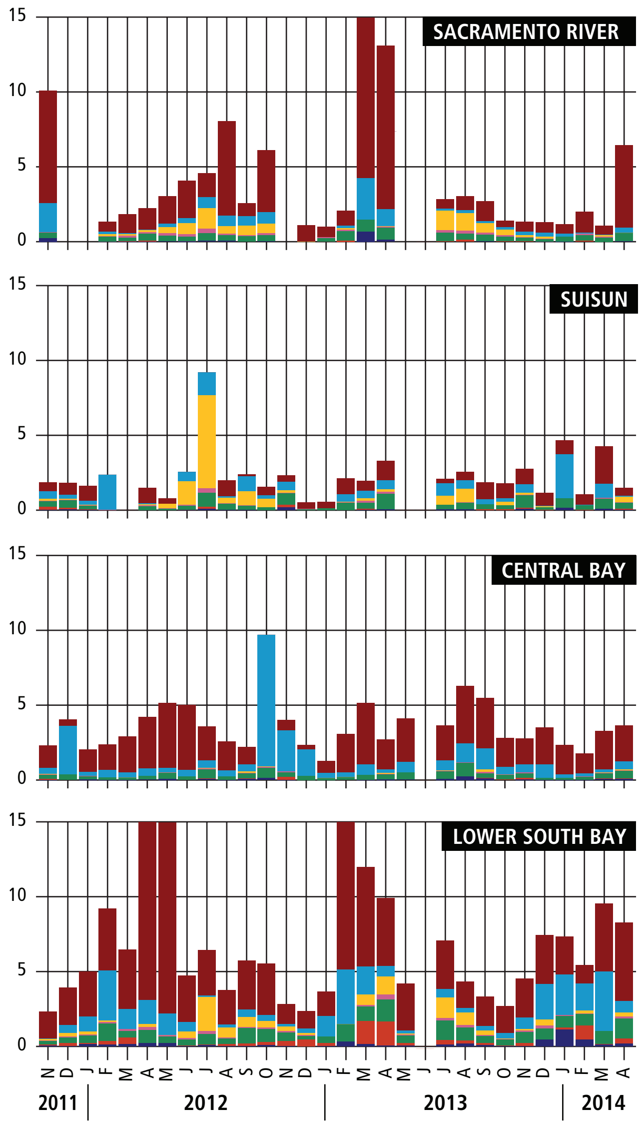
ALVISO SLOUGH



Data from moored sensors deployed by SFEI. Note different scales on y-axes. Additional details on page 61.

Nutrients: Phytoplankton Community Composition and Toxins

ABUNDANCE OF PHYTOPLANKTON TYPES



Chlorophyll a in µg/L. Data from M. Peacock (UC Santa Cruz). Additional details on page 61.

Phytoplankton are the base of the food web in San Francisco Bay. Both the amount of phytoplankton and the types of phytoplankton – the community composition – are highly relevant to the ecological status and function of the Bay, since different classes of phytoplankton can have different nutritional values. In addition, some phytoplankton produce toxins. Investigations are underway to characterize community composition in the Bay, identify the physical factors and chemical factors (including nutrients) that influence community composition and toxin production, and identify the most informative and efficient ways to monitor for these indicators of ecosystem health.

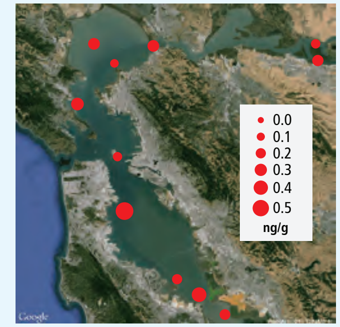
Different classes of phytoplankton have unique pigment fingerprints. Pigments can be measured in environmental samples and used to back-calculate the types of phytoplankton that are contributing to biomass. Pigment measurements are faster and more cost-effective than microscopy and also better estimate the abundance of some small classes that are difficult to see and may be underestimated by microscope (i.e., cyanophytes).

Three years of monthly phytoplankton community composition estimates (left) show considerable seasonal and spatial variability in phytoplankton assemblage. In general, diatoms tend to dominate, especially when chlorophyll is elevated, except in Suisun Bay where biomass is low and distributed among multiple classes.

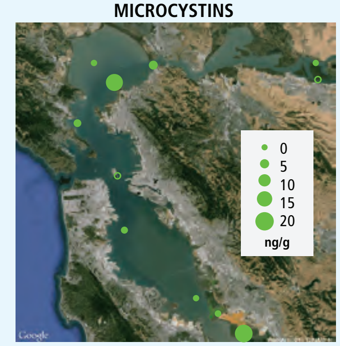
PHYTOPLANKTON CLASS

- Diatom
- Dinoflagellate
- Cyanophyte
- Chlorophyte
- Cryptophyte
- Eustigmatophyte
- Other

DOMOIC ACID



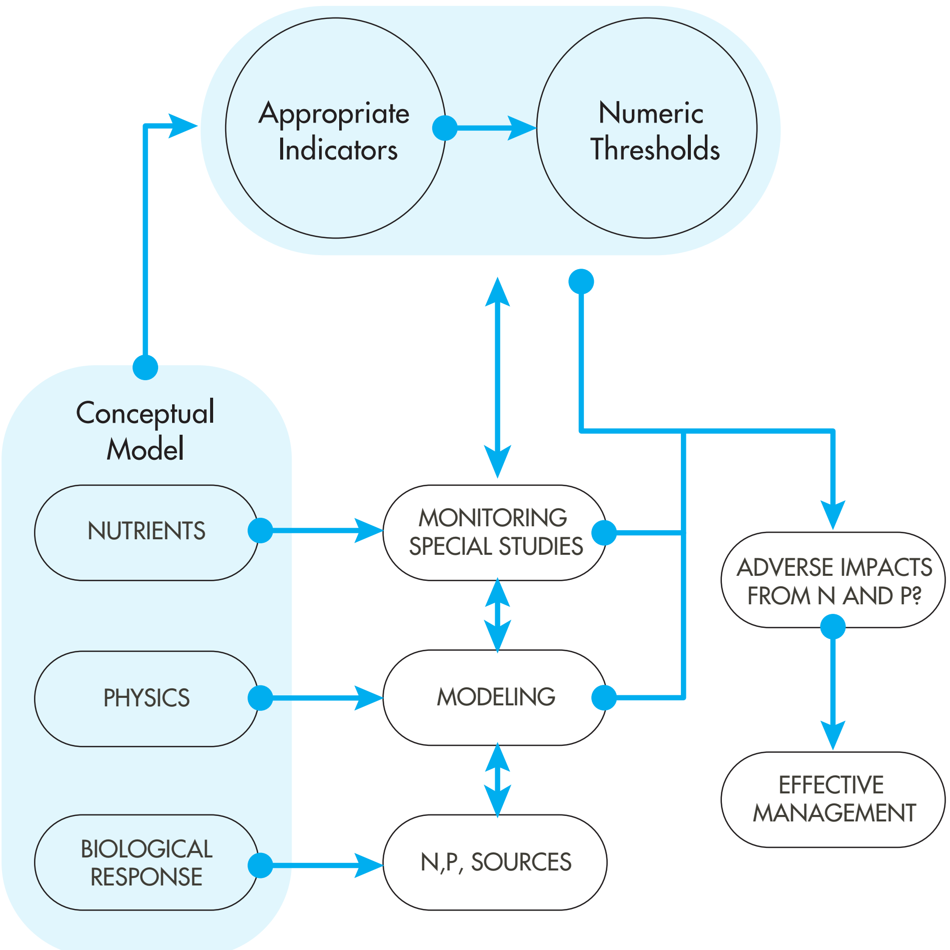
MICROCYSTINS



Mussels were analyzed for the algal toxins domoic acid, microcystin, and saxitoxin in 2012. Domoic acid was detected at all sites, microcystin was detected at 10/11 sites, and saxitoxin (not shown) was detected at 5/11 sites. **Although these data suggest that toxins are ubiquitous, the concentrations were low relative to existing standards.** SFEI is working with UC Santa Cruz and the US Geological Survey to continue sampling for these toxins.

Nutrients: Next Steps

FLOW DIAGRAM OF THE NUTRIENT MANAGEMENT STRATEGY FOR SAN FRANCISCO BAY



Scientific investigations and monitoring are underway, or planned to:

- identify appropriate nutrient-related indicators and numeric thresholds for those indicators,
- determine when and where adverse impacts occur,
- determine protective nutrient levels,
- quantify loads,
- model transport and fate within the Bay, and
- ultimately identify effective management actions if they are needed.

Because physical and biological factors play a strong role in regulating an estuary's response to nutrients, N and P concentrations alone are not good indicators of ecological health. Instead, indicators of biological response to nutrients are considered to be more meaningful. Some potential indicators are familiar – e.g., chlorophyll and dissolved oxygen as indicators of unhealthy primary production rates. Even for these traditional indicators, however, numeric thresholds may differ by subembayment or habitat.

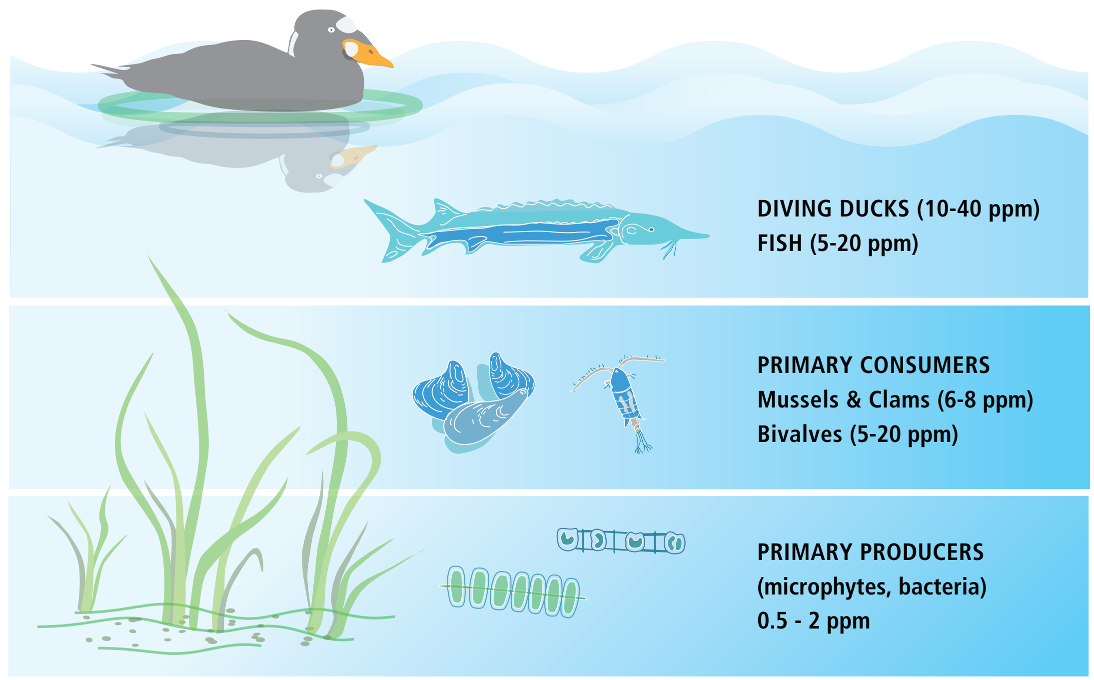
Other potential adverse impact pathways, besides low dissolved oxygen, are also being examined. Some of these pathways have unique indicators, such as abundance of potentially harmful algal species and algal toxin concentrations, or phytoplankton assemblage as an indicator of food quality.

Selenium: Summary; Recent Advances

KEY POINTS

- Average selenium concentrations in the Bay food web in recent years have been below thresholds for adverse effects in fish and wildlife, but a few samples have exceeded the thresholds
- A TMDL for the North Bay and specific criteria for the Bay are in development
- Concentrations in white sturgeon, a key indicator species, have been fairly constant since the mid-1990s
- White sturgeon from the South Bay region have been slightly lower in selenium than North Bay sturgeon

SELENIUM CONCENTRATIONS IN THE NORTH BAY FOOD CHAIN



RECENT ADVANCES

Average selenium concentrations in the Bay food web in recent years are below thresholds for adverse effects in fish and wildlife, but a few samples have exceeded the thresholds. Concern for risks to aquatic life is the primary impetus for a control plan for the North Bay (the North Bay Selenium TMDL) that is being developed by the Water Board. In another regulatory initiative, USEPA is developing specific selenium criteria to protect threatened and endangered wildlife species in the Bay - these criteria will be proposed by June 2016.

A substantial amount of scientific study has been conducted to support development of the TMDL and the revised criteria, including an ecosystem-scale selenium model (Presser and Luoma 2013), a model of transport, fate, and uptake into the food web (Chen et al. 2012b), and additional monitoring and review (http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/TMDLs/seleniumtmdl.shtml).

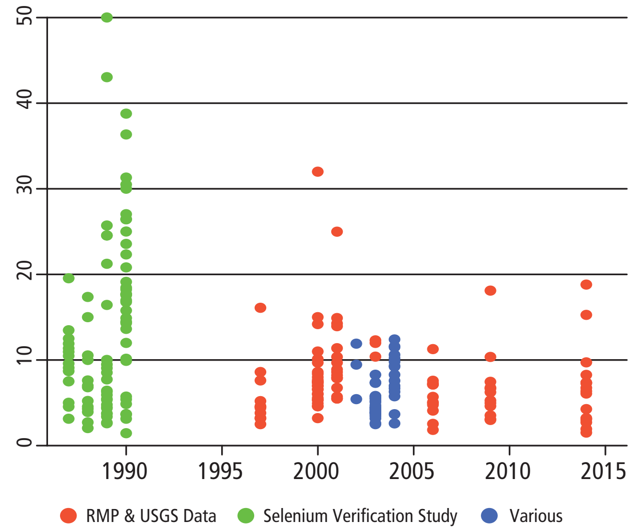
Long-term trend monitoring by the RMP and USGS also continues. The RMP measures selenium regularly in water (page 51), sediment, sport fish (including sturgeon) (page 50), and bird eggs (page 50). USGS recently published a summary of findings from their near-monthly monitoring of clams in the North Bay since 1995 (Stewart et al. 2013).

Selenium: Impairment

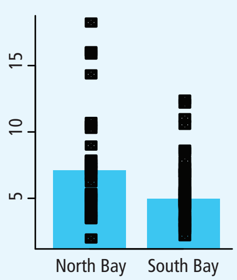
White sturgeon, a species that preys on clams and other bottom-dwelling invertebrates, is recognized as a key indicator of selenium impairment in the North Bay due to its susceptibility to selenium bioaccumulation. Monitoring of selenium in sturgeon by the RMP and other programs suggests that concentrations were relatively high in 1989 and 1990, but fairly constant in other years and not trending up or down. A target of 11.8 ppm in white sturgeon muscle has been proposed in the draft TMDL for selenium in the North Bay. Average selenium concentrations in the Bay food web in recent years have been below the target, but a few samples have exceeded it.

All graphs: All data in ppm dry weight. Data from the RMP and other sources. Additional details on page 61.

SELENIUM IN WHITE STURGEON



White sturgeon collected south of the Bay Bridge have had slightly lower concentrations of selenium than North Bay sturgeon. This observation has been made in spite of the high selenium concentrations in water of Lower South Bay (south of the Dumbarton Bridge). After completion of the North Bay TMDL, managers and scientists will focus on evaluating the status of the South Bay.

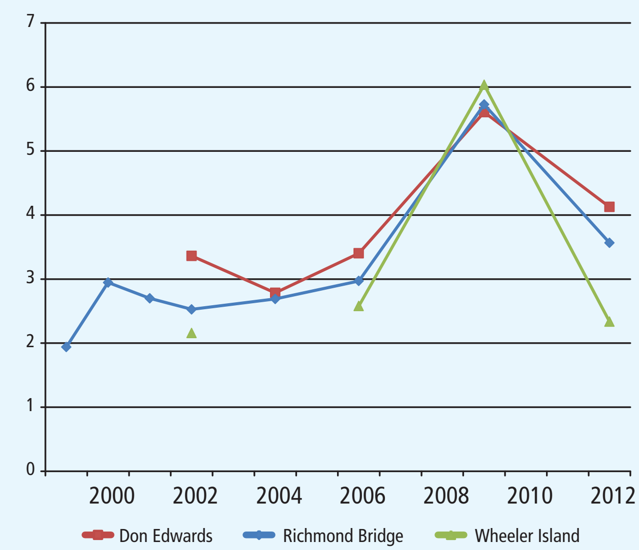


Se concentrations (ppm dry weight) in white sturgeon.

Avian predators of fish and aquatic invertebrates can also be at risk from selenium accumulation, and avian eggs are therefore another valuable indicator of potential impairment. A selenium standard of 12.5 ppb in bird eggs was recently approved for Great Salt Lake. The RMP has tracked selenium concentrations in double-crested cormorant eggs for over 10 years (left). The highest concentration measured was 8.7 ppb in 2009. Concentrations were unusually high in 2009, and relatively constant in the other years sampled.

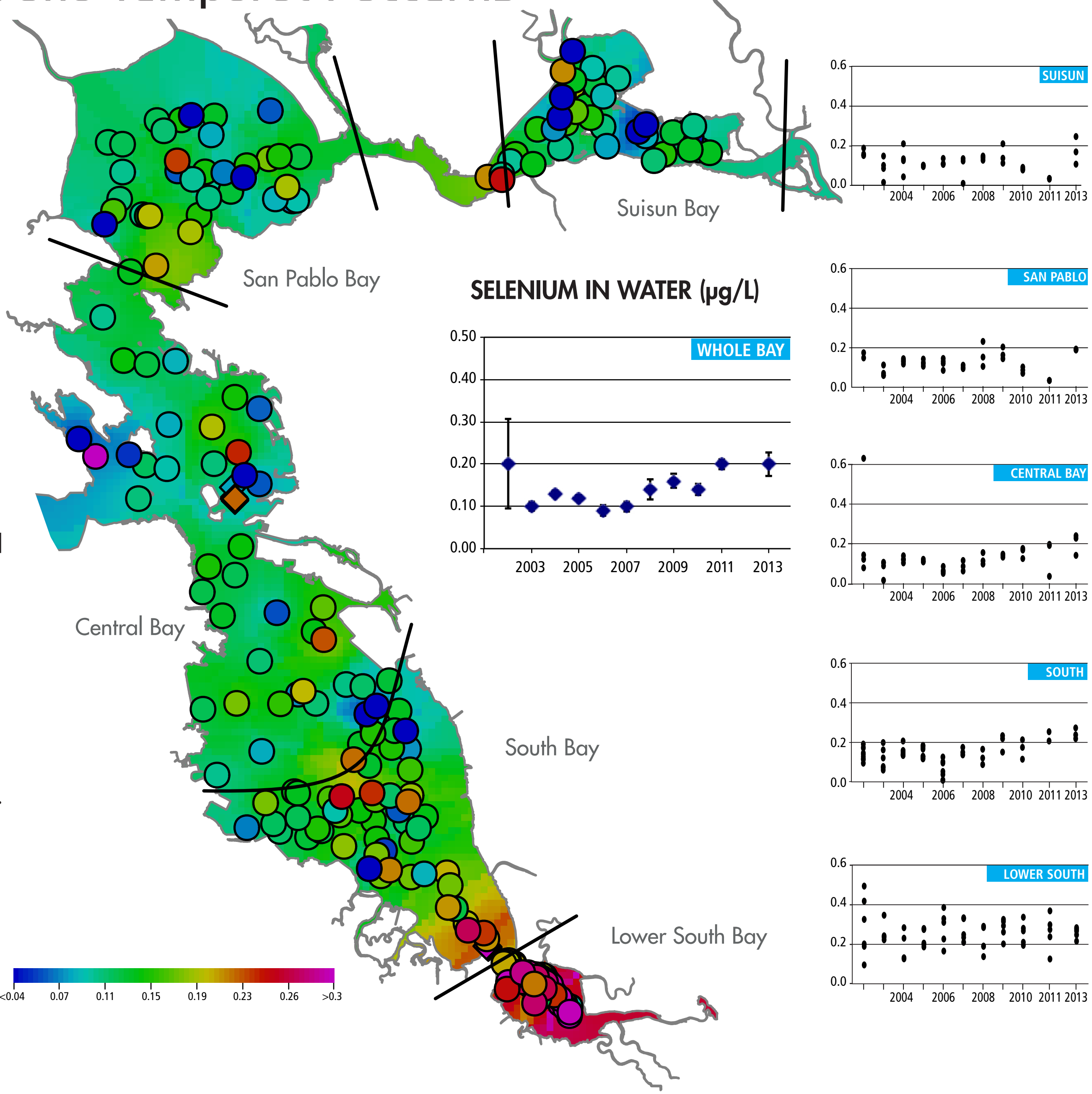
Average Se concentrations (ppm dry weight) in cormorant egg composites.

SELENIUM IN CORMORANT EGGS



Selenium: Spatial and Temporal Patterns

Although food web monitoring is needed as a direct measure of impacts to wildlife, concentrations in water are another index of potential water quality impairment and have been monitored by the RMP for over 20 years. The Lower South Bay had a higher average concentration over this period (0.25 µg/L) than the other Bay segments, which had very consistent average concentrations (all between 0.13 and 0.15 µg/L). The highest concentration observed in water at random stations from 2002 to 2013 was 0.63 µg/L (in Central Bay in 2002). The Bay-wide average concentrations in 2011 and 2013 (0.20 µg/L) were higher than the Bay-wide average for 2002-2013 (0.14 µg/L). Concentrations appear to have been rising in Central Bay and South Bay over the last few rounds of sampling - continued monitoring will determine whether this is indicative of a long-term trend.

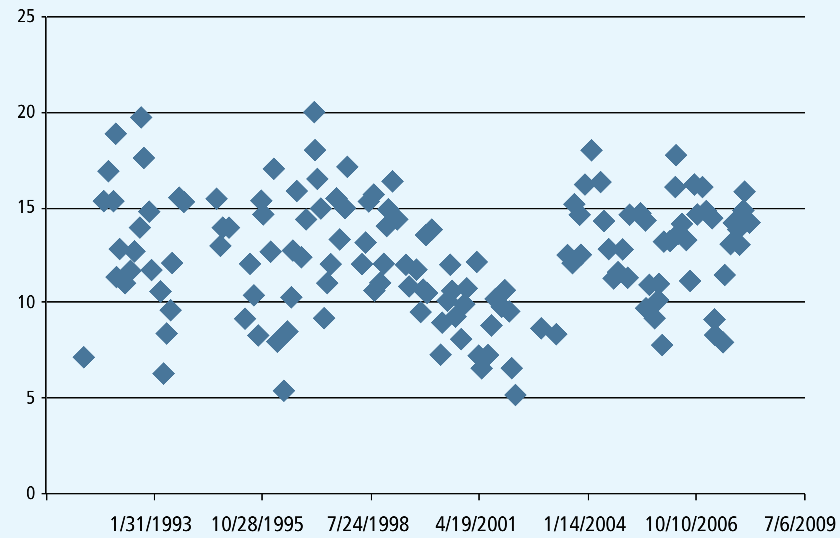


Contours and points on the map show all available dry season data from 2002-2013. Sampling was not performed in 2012. Bay-wide trend plot shows annual random-station means with error bars indicating the 95% confidence intervals of the means. Additional details on page 61.

Selenium: Sources, Pathways, and Loadings; Next Steps

Selenium loads to the North Bay have been quantified as part of development of the TMDL. Anthropogenic sources of selenium to the Bay, including agricultural inputs via the San Joaquin River and refinery discharges, have been reduced over the last decade. Refinery loads have been reduced from approximately 2000 kg/yr in the late 1980s to 570 kg/yr from 2009-2012. Refinery loads are now of a similar magnitude as local tributary loads. Loads from the Central Valley are the greatest by a wide margin. In spite of the refinery load reductions, however, selenium concentrations in the food web are still occasionally higher than levels commonly associated with toxicity and reproductive impairment in fish and other wildlife species. After refinery treatment began in 1998, clam selenium concentrations declined to levels 50% of pre-1998 concentrations for a few years, but then returned to levels comparable to previous measurements.

SELENIUM IN CLAMS



Se concentrations (ppm dry weight) in Corbula amurensis at Carquinez Strait (station 8.1). Data from Kleckner et al. (2010).

SELENIUM LOADS TO THE NORTH BAY (kg/year)

PATHWAY	BAGINSKA (2015): CEQA SCOPING MEETING
POTWs	110
Refineries	570
Local Tributaries	520
Central Valley	4070

Completion of the North Bay TMDL and site-specific criteria for the Bay will be important regulatory milestones that define future monitoring needs. The Water Board also envisions consideration of a TMDL for the South Bay after the North Bay TMDL is completed. In the meantime, the RMP is focusing on improving information on impairment through more extensive monitoring of white sturgeon. Non-lethal sampling of muscle plugs from sturgeon, in collaboration with the California Department of Fish and Wildlife, began in 2014 and promises to greatly expand this critical dataset. The RMP Selenium Workgroup is also considering other studies to address priority information needs.

Contaminants of Emerging Concern

KEY POINTS

- The RMP has pioneered a forward-looking strategy on emerging contaminants that can help prevent new pollution problems
- The tiered CEC management and monitoring framework (right) guides monitoring priorities
- A decade of RMP monitoring has documented declines in toxic flame retardants known as PBDEs following a halt in US production
- Cutting edge non-targeted analysis of Bay mussels and harbor seal blubber revealed few unexpected contaminants

	TIER ASSIGNMENTS	MANAGEMENT	MONITORING
TIER 4 HIGH CONCERN	No CECs currently in this tier	303(d) listing TMDL or alternative management plan Aggressive control actions for all controllable sources	Studies to support TMDL or an alternative management plan
TIER 3 MODERATE CONCERN	PFOS Fipronil Nonylphenol and nonylphenol ethoxylates PBDEs	Action plan or strategy Aggressive pollution prevention Low-cost control actions	Consider including in Status and Trends Monitoring Special studies of fate, effects, and sources, pathways, and loadings
TIER 2 LOW CONCERN	HBCD Pyrethroids * Pharmaceuticals and personal care products PBDDs and PBDFs	Low-cost source identification and control Low-level pollution prevention Track product use and market trends	Discontinue screening, or periodically screen in water, sediment, or biota Periodic screening in wastewater effluent or urban runoff to track trends
TIER 1 POSSIBLE CONCERN	Alternative flame retardants Pesticides Plasticizers Many, many others	Identify and prioritize contaminants of potential concern, track international efforts Develop targeted and non-targeted analytical methods	Screening in water, sediment, biota, wastewater effluent, urban runoff

* *Pyrethroids are of low concern in the Bay, but high concern in Bay Area urban creeks*

RECENT ADVANCES

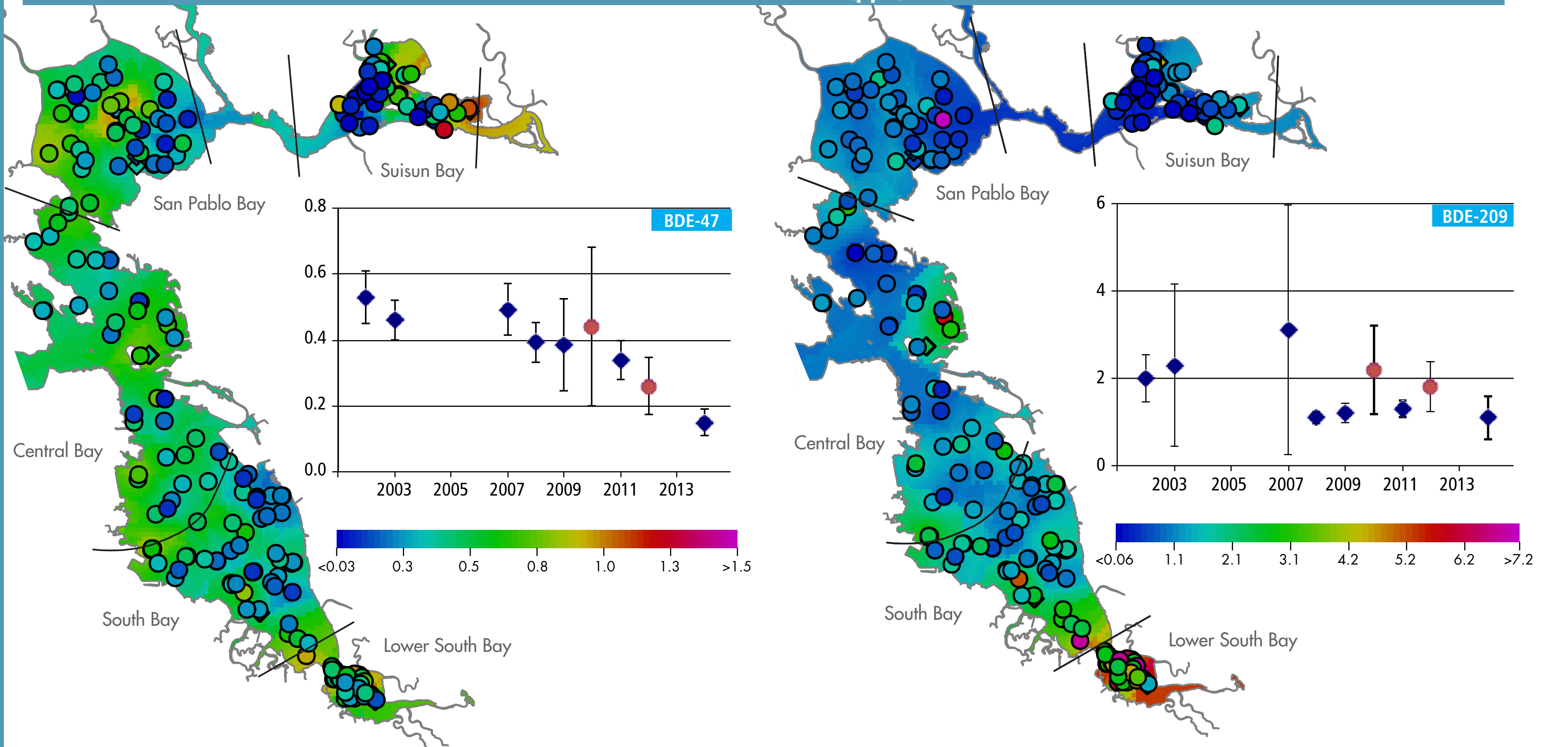
In 2013, the RMP published a CEC Strategy with three elements: 1) targeted chemical monitoring and risk evaluation; 2) review of scientific literature and other monitoring programs to identify new CECs for study; and 3) non-targeted analysis to create inventories of contaminants in tissues, sediment, or water that can be used to direct targeted chemical monitoring or toxicity identification evaluations (Sutton et al. 2013).

A tiered, risk-based framework guides monitoring and management actions for CECs detected in the Bay (above). Extensive monitoring has not identified any "high concern" CECs causing significant impacts to Bay wildlife. Four "moderate concern" CECs may cause low level impacts to wildlife: perfluorooctane sulfonate (PFOS), the pesticide fipronil, nonylphenol ethoxylate surfactants and their endocrine-disrupting breakdown product nonylphenol, and polybrominated diphenyl ether (PBDE) flame retardants.

The RMP's CEC program is currently developing new or expanded data on PFOS and other poly- and perfluorochemicals (e.g., current and past ingredients in Teflon and Scotchgard), PBDEs and alternative flame retardants, fipronil, and micro-plastics.

Contaminants of Emerging Concern: PBDEs

PBDES IN SEDIMENT (ppb)



Contours and points on the map show all available dry season RMP data from 2002-2014. Trend plots show annual random station means with error bars indicating the 95% confidence intervals of the means. Red circles on trend plots indicate wet season samples; other samples were dry season. Additional details on page 61.

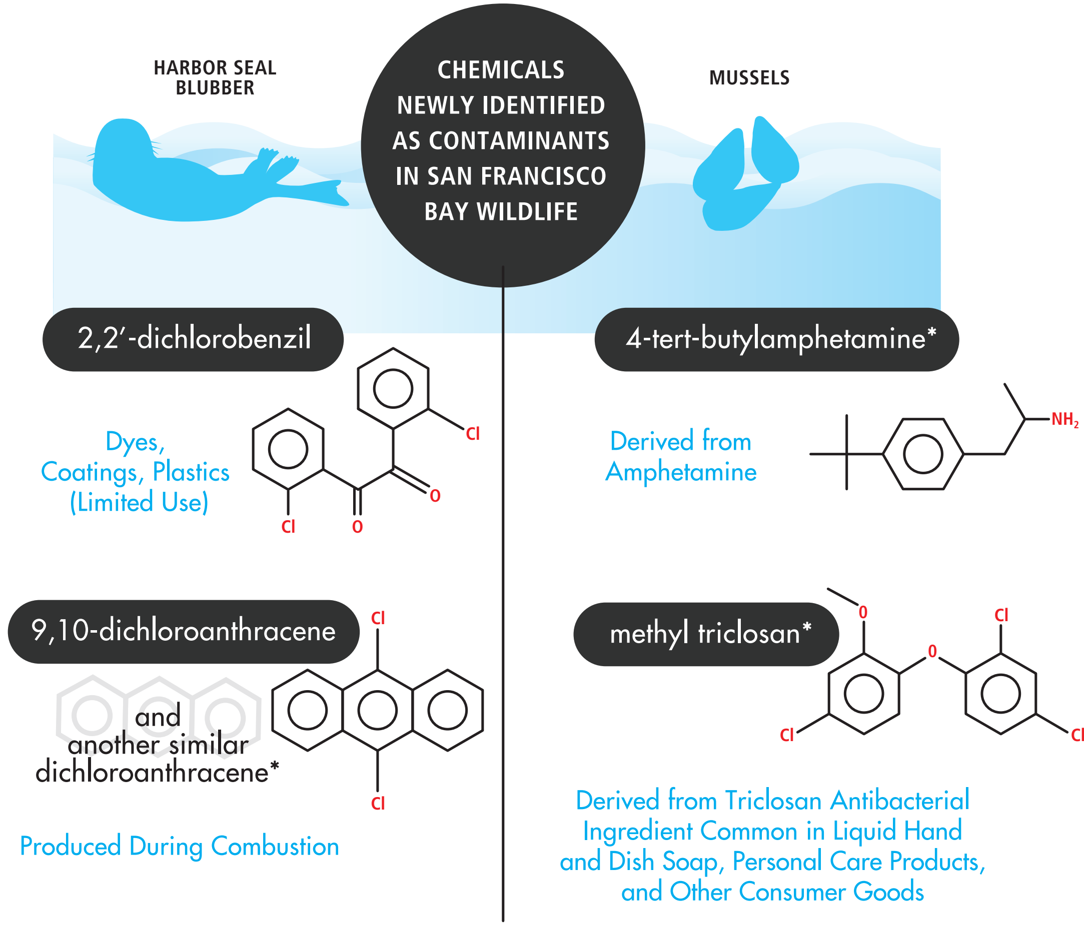
RMP monitoring of PBDEs documented a pollution prevention success story. A state ban and industry phase-out of two commercial mixtures of the toxic flame retardants known as polybrominated diphenyl ethers (PBDEs) led to significant declines in BDE-47, a major component of the Penta mixture, in Bay sediment (left) and wildlife. A third commercial mixture of PBDEs, known as Deca, was phased out in 2013; levels of BDE-209, the major component of this mixture, have not yet shown clear declines (right). This RMP success story was published in *Environmental Science and Technology*, a leading environmental science journal (Sutton et al. 2015).

Contaminants of Emerging Concern: Broadscan Analysis

A RMP study employed a cutting edge analytical technique to detect low levels of five unmonitored compounds in wildlife of San Francisco Bay. San Francisco Bay wildlife were tested using a non-targeted analysis that screens mainly for long-lived, fat-soluble, chlorine- and bromine-rich chemicals. Bay mussel and harbor seal samples contained five contaminants not previously identified in Bay wildlife, and for which toxicity is largely unknown. Contaminants were measured semi-quantitatively at levels of less than 1 part per billion (ppb) up to roughly 20 ppb. The detection of these compounds suggests that the original or "parent" contaminants may not always be the most important chemical to monitor.

Most of the Bay chemical contamination was from high priority contaminants that the RMP already monitors, or closely related compounds. This suggests that many of the highest priority persistent chlorinated and brominated chemicals have already been identified, with key contaminants regularly monitored.

Future non-targeted analysis could include techniques that examine water-soluble compounds. Examples include many cleaning and personal care product ingredients, contaminant breakdown products or metabolites, and chemicals that associate with protein-rich tissues like blood rather than fats. Although some of these water-soluble chemicals do not linger long in the environment, they are widely used and may be continuously discharged to the Bay at relatively high levels, potentially leading to prolonged exposure and toxicity to aquatic life.



* Identifications have not yet been confirmed by comparison with a pure compound

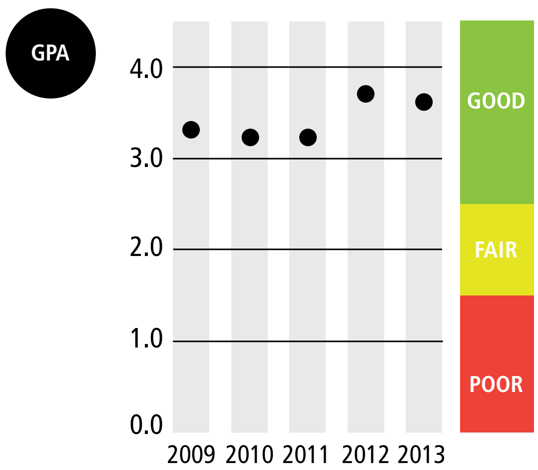
Fact sheet on this study available at: http://www.sfei.org/broadscan

Beach Pathogens

KEY POINTS

- Pathogenic organisms found in waste from humans and other warm-blooded animals can pose health risks to people who recreate in contaminated waters
- Six Bay beaches are on the 303(d) List of impaired water bodies because fecal indicator bacteria exceed water quality standards, and a TMDL is under development to address this impairment
- For Bay beaches overall, in the summer of 2013 conditions were excellent (A grade) at 79% (22 of 28) of beaches in the summer, and at a slightly lower percentage of beaches (64%, 14 of 22) in wet weather
- The Bay-wide average summer grade (right) has been fairly constant over the past five years

BEACH REPORT CARD GRADES



Data from Heal the Bay (2014). Graph details on page 61.

RECENT ADVANCES

Swimming, wading, surfing, windsurfing, kite-surfing, and fishing in the Bay can expose people to potentially infectious pathogens, including bacteria, viruses, and protozoa originating from the intestines of warm-blooded animals. While the health risks are generally neither chronic nor severe, swimming-related illnesses can occur frequently enough to merit concern.

County public health and other agencies routinely monitor fecal indicator bacteria (FIB) concentrations at 28 Bay beaches where water contact recreation is common and provide warnings to the public when concentrations exceed the standards. Using these data, Heal the Bay, a Santa Monica-based non-profit, provides evaluations of over 400 California bathing beaches in Beach Report Cards as a guide to aid beach users' decisions concerning water contact recreation (Heal the Bay 2014).

Overall, the latest beach report card covering the summer of 2013 indicated that conditions were excellent (A grade) at 79% (22 of 28) of Bay beaches in the summer, and at a lower percentage of beaches (64%, 14 of 22) in wet weather. Two beaches (7%) were in poor condition (D or F grades) in summer, while 6 of 22 beaches (27%) were in poor condition in wet weather. The Bay-wide average summer grade (above) has been fairly constant over the past five years.

Beach Pathogens

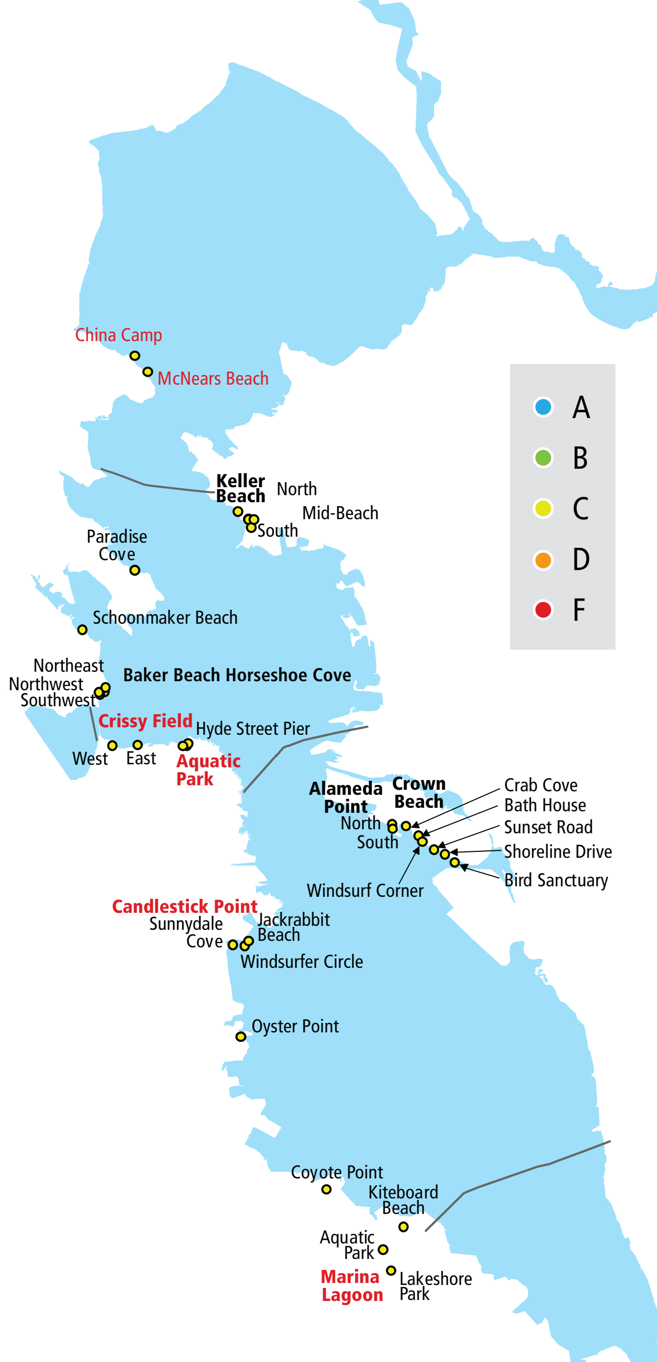
Grades from Heal the Bay report cards, which use the familiar "A to F" letter grade scale, provide an assessment of how safe Bay waters are for swimming. Overall, the monitoring data and resulting grades (right) indicate that most Bay beaches are safe for summer swimming, but that bacterial contamination is a concern at a few beaches in the summer, and at some beaches in wet weather.

Data for the summer beach season in 2013 are available for 28 beaches. In 2013, 22 of the 28 monitored beaches received an A or A+ grade, reflecting minimal exceedance of standards. Four of these beaches received an A+: Crown Beach Bath House, Crown Beach Windsurf Corner, Jackrabbit Beach and Candlestick Point, and Horseshoe Cove SW at Baker Beach. Most Bay beaches, therefore, are quite safe for swimming in the summer.

Six of the 28 beaches monitored in the summer in 2013 had grades of B or lower, indicating varying degrees of exceedance of bacteria standards. Aquatic Park and Lakeshore Park in San Mateo County received an F. These low grades indicate an increased risk of illness or infection.

Overall, the average grade for the 28 beaches monitored from April-October was an A-.

During wet weather, which mostly occurs in the winter, water contact recreation is less popular but is still enjoyed by a significant number of Bay Area residents. Bacteria concentrations are considerably higher in wet weather due to stormwater runoff and sewer overflows, making the Bay less safe for swimming. This pattern is evident in the 2013-2014 report card grades for wet weather. In wet weather, six of 22 beaches with data (27%) had grades of D or F. Many of the beaches (14 of 22, 64%), however, still had grades of A or A+. The overall average grade for these 22 beaches in wet weather was a B.



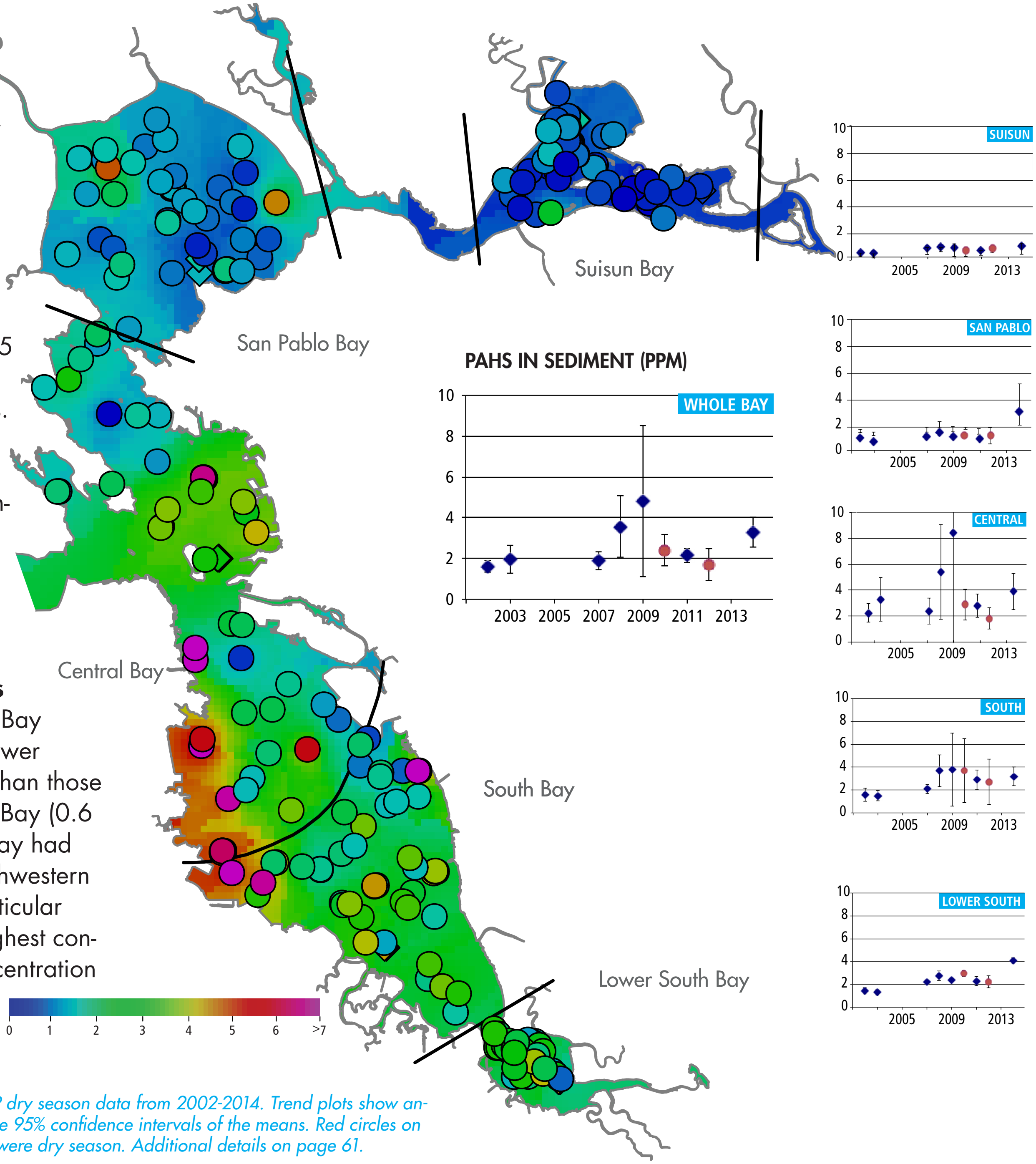
		2011	2012	2013
SAN MATEO COUNTY				
Oyster Point		D	A	A
Coyote Point		A	A	A
Marina Lagoon	Aquatic Park	F	F	F
	Lakeshore Park	F	D	F
Kiteboard Beach			A	C
ALAMEDA COUNTY				
Alameda Point	North	A	A	A
	South	A	A	A
Crown Beach	Crab Cove			A
	Bath House	A	A	A
	Windsurf Corner	A	A	A
	Sunset Road	A	A	A
	Shoreline Drive	A	A	A
	Bird Sanctuary	B	A	A
CONTRA COSTA COUNTY				
Keller Beach	North	B	A	A
	Mid-Beach	B		
	South	B	A	A
SAN FRANCISCO COUNTY				
Crissy Field Beach	West	A	A	A
	East	A	A	A
Aquatic Park Beach	211 Station	B	A	A
	Hyde Street Pier	A	A	A
Candlestick Point	Jackrabbit Beach	B	A	A
	Windsurfer Circle	B	C	C
	Sunnydale Cove	A	A	B
MARIN COUNTY				
Baker Beach Horseshoe Cove	NE	B	A	A
	NW	A	A	A
	SW	A	A	A
Schoonmaker Beach		B	A	A
China Camp		A	A	A
McNears Beach				B

Beach summer water quality grades for 2011-2013. Beach names listed in red are included in the Bay Beaches TMDL. Data from Heal the Bay (2014). See page 61 for additional details.

PAHs

PAH concentrations in Bay sediment may be trending upward. The average concentration in the latest round of sampling in 2014 (3.3 ppm) was relatively high, and unlike the high averages observed in 2008 and 2009, was not driven by a few unusually contaminated sites. The Bay-wide average is approaching the 4.5 ppm trigger for bioaccumulation testing in dredged material disposal evaluations. Concentrations within each segment appear to be on the rise. Further rounds of sampling are needed to determine whether this pattern is truly indicative of a long-term increase.

PAH concentrations are higher in the southern arm of the Bay, likely due to runoff from the extensive paved surfaces in this region. Concentrations in Central Bay (4.1 ppm), South Bay (2.7 ppm), and Lower South Bay (2.2 ppm) have been higher than those in San Pablo Bay (1.2 ppm) and Suisun Bay (0.6 ppm). In 2014, however, Lower South Bay had the highest average (4.1 ppm). The southwestern shoreline of Central Bay has been a particular hotspot, with a cluster of many of the highest concentrations, including the maximum concentration of 43 ppm in 2009.



Contours and points on the map show all available RMP dry season data from 2002-2014. Trend plots show annual random-station means with error bars indicating the 95% confidence intervals of the means. Red circles on trend plots indicate wet season samples; other samples were dry season. Additional details on page 61.

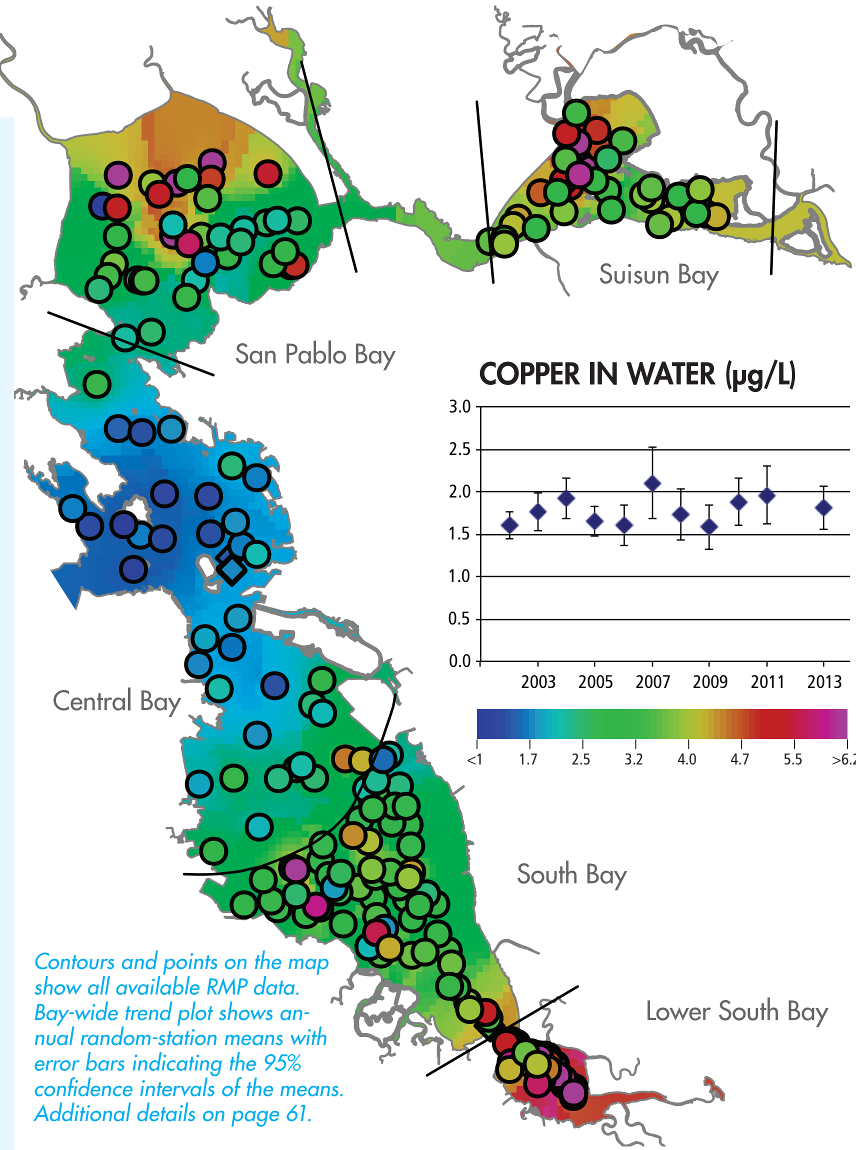
Copper

Copper in the Bay was a major concern in the 1990s. An evaluation of the issue by the Water Board and stakeholders, based on an extensive dataset provided by the RMP and other studies showing that most of the copper in the Bay is bound up in a harmless form, concluded that the existing water quality objectives were inappropriately low. These findings led to new Bay-specific water quality objectives for copper (less stringent but still considered fully protective of aquatic life), pollution prevention and monitoring activities to make sure concentrations remain below the objectives, and the 2002 removal of copper from the 303(d) List of pollutants of concern in the Bay.

In order to determine that concentrations have not increased, monitoring data collected by the RMP are compared to specific trigger levels. If the trigger concentration is exceeded in any Bay segment, the Water Board will investigate causes of the exceedance and consider potential control options. Concentrations in the most recent assessment period were below the triggers (lower right).

Until recently, one remaining concern was that exposure to dissolved copper has been shown to cause olfactory impairment in salmon in freshwater at concentrations that are lower than the Bay-specific objectives. However, the potential impacts of copper to the olfactory system of salmonids in saline waters like the Bay was unknown. To address this data gap, the RMP, in partnership with the Copper Development Association (a copper industry trade group), funded studies on the sensitivity of salmon olfaction to copper exposure in the range of salinities found in the Bay. The studies indicated that salmon sensitivity in saline or moderately saline water is much lower than in freshwater, and that the potential effect of copper on olfaction is not a concern for salmon migrating through the Bay (Baldwin 2015).

To maintain water quality in the Bay, municipalities are required to implement actions to control discharges to storm drains from architectural (e.g., roofs) and industrial (e.g., metal plating) uses of copper, as well as copper used as an algaecide in pools, spas, and fountains. They are also required to address vehicle brake pads, the largest source of copper to the Bay, which they have done through participation in the Brake Pad Partnership, a public-private collaboration whose work led to the passage of legislation (SB 346) requiring that the amount of copper in brake pads sold in California be reduced to no more than 0.5% by 2025.



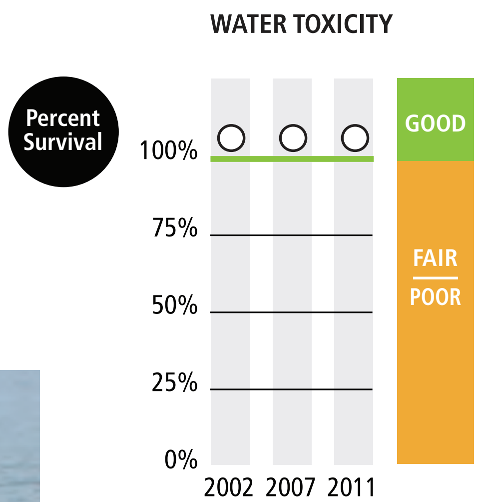
Contours and points on the map show all available RMP data. Bay-wide trend plot shows annual random-station means with error bars indicating the 95% confidence intervals of the means. Additional details on page 61.

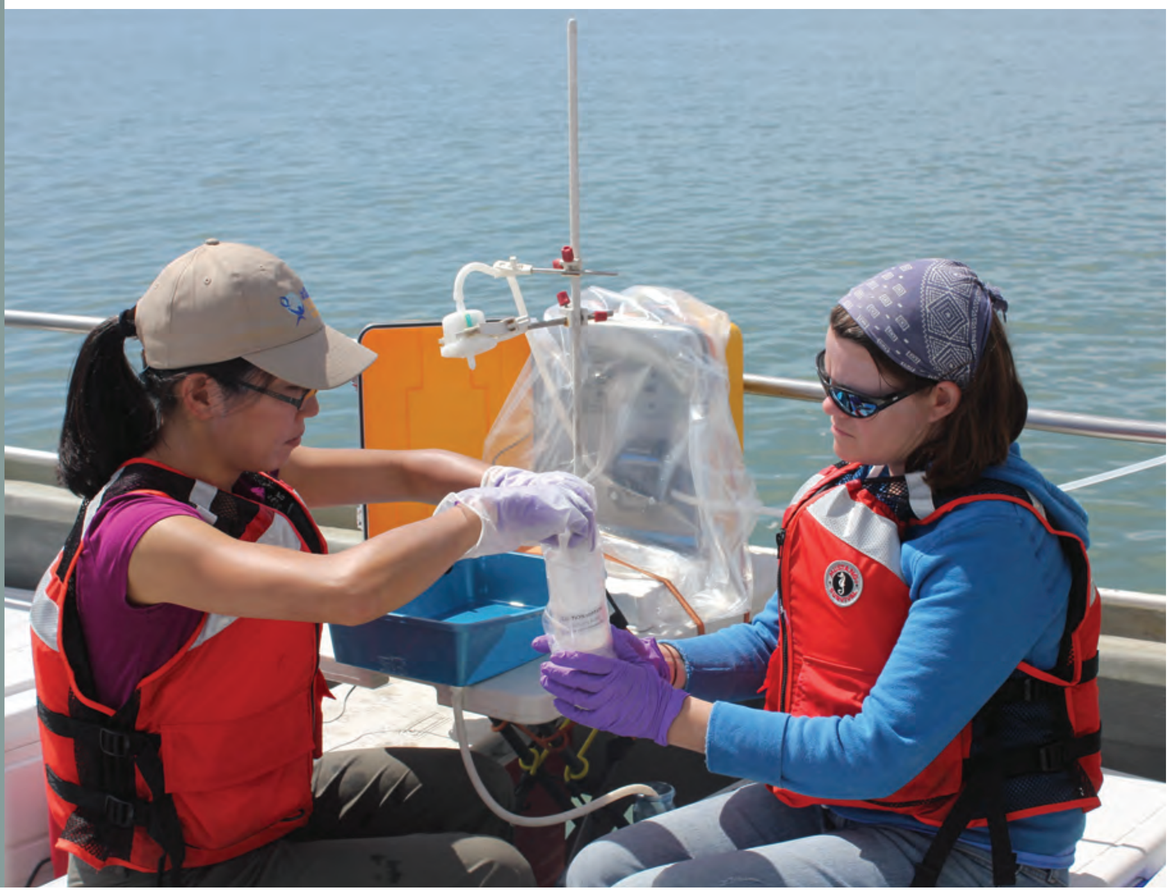
BAY SEGMENT	TRIGGER (µg/L)	2010-2013 ROLLING AVERAGE (µg/L)
LOWER SOUTH BAY	4.2	3.9
SOUTH BAY	3.6	2.8
CENTRAL BAY	2.2	1.5
SAN PABLO BAY	3.0	2.1
SUISUN BAY	2.8	2.2

Toxicity

Toxicity tests are laboratory procedures designed to determine whether contaminant levels in water or sediment samples from the Bay might impact aquatic life. Water quality objectives for the Bay prohibit the presence of contaminants in toxic amounts. Toxicity tests are used to monitor compliance with these objectives.

No water toxicity has been observed in the Bay in recent sampling. The water quality objective for water toxicity has therefore been met consistently over the past 10 years.





RMP water sampling. Photograph by Paul Salop.

Graph Details

All RMP data are available through the RMP website: www.sfei.org/rmp

Page 33

Sport fish data from Davis et al. (2011). Small fish data from Greenfield et al. (2013a,b). Thresholds for sport fish are advisory tissue levels from the Office of Environmental Health Hazard Assessment. Threshold for small fish is the water quality objective established as part of the mercury TMDL.

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Top and Bottom: "ATL No Consumption" is the Office of Environmental Health Hazard Assessment advisory tissue level of 0.44 ppm calculated to protect women aged 18-45 years and children aged 1-17 years. Water quality objective is 0.2 ppm.

Bottom: To correct for variation in fish length, all plotted data have been calculated for a 60-cm fish using the residuals of a length vs. log(Hg) relationship.

Page 35

All concentrations for total mercury on a dry weight basis.

Map plot: Circles represent random sites. Diamonds represent historic fixed stations. Data from wet season sampling and historic stations were excluded from the contour generation.

Page 36

Fish species: LOMU - longjaw mudsucker; MISI - Mississippi silversides; PAHE - Pacific herring; RAKI - rainwater killifish; SHGO - Shimofuri goby; STSC - staghorn sculpin; THST - threespine stickleback; TOSM - topsmelt; YEGO - yellowfin goby

Page 37

Sport fish data from Davis et al. (2011). Thresholds for sport fish are advisory tissue levels from the Office of Environmental Health Hazard Assessment.

Page 38

Top and Bottom: "ATL No Consumption" is the Office of Environmental Health Hazard Assessment advisory tissue level of 120 ppb. Water quality objective is 10 ppb. Data from Davis et al. (2011).

Page 39

All concentrations for sum of PCBs (RMP 40 congeners) on a dry weight basis.

Map plot: Circles represent random sites. Diamonds represent historic fixed stations. Data from wet season sampling and historic stations were excluded from the contour generation.

Page 40

All data for sum of PCBs (RMP 40 congeners).

Graph: Data from Davis et al. (2014).

Page 41

All data for sum of PCBs (RMP 40 congeners). Data from Greenfield and Allen (2014).

Page 43

Chlorophyll a averaged over the top 2 meters during August-October at stations s21, s22, s24, s25, s27, s29, s30, and s32. Data collected monthly at fixed stations along the spine of the Bay. Data from USGS: sfbay.wr.usgs.gov/access/wqdata.

Page 44

A: Nutrient loads, 2005-2011. Delta loads were estimated using flow and concentration data, similar to the method in Jassby and Cloern (2000). POTW loads were estimated using either actual reported effluent data or a combination of flow and best estimates for effluent composition based on treatment type. Stormwater loads estimated using the Regional Watershed Spreadsheet Model (Lent and McKee 2011) and best estimates of land-use specific nutrient concentrations.

B: DIN concentrations, averaged over the entire water column, for Suisun Bay (station s6), Central Bay (station s18) and Lower South Bay (s36). The box extends from the 25th percentile to the 75th percentile. Data collected monthly at fixed stations along the spine of the Bay. Data from USGS: sfbay.wr.usgs.gov/access/wqdata.

Page 45

Top: Data collected monthly at USGS stations s34 and s36 and South Bay Dischargers Authority (SBDA) monitoring station SB5, also located in the main channel of LSB. The box extends from the 25th percentile to the 75th percentile.

Bottom: Loads were calculated based on reported effluent flow/concentration data by the three major dischargers to LSB. There are some years where data was not available for Sunnyvale and Palo Alto.

Page 46

Top: Minimum DO (% saturation) at sites s21 – s34. Data collected monthly at fixed stations along the spine of the Bay. Data from USGS: sfbay.wr.usgs.gov/access/wqdata.

Bottom: Data collected via a moored sensor at 15-minute intervals. Note the different y-axis scales.

Page 47

Left: Chl-a concentration by major phytoplankton class for the Delta (s649), Suisun Bay (s6), Central Bay (s18) and Lower South Bay (s34 or s36, whichever was sampled on a given day). Chl-a concentrations per class were estimated by analysis of algal pigment samples collected 1-2x monthly at fixed stations.

Right: Algal toxin concentrations (ng/g) detected in mussels deployed in SFB, June-September 2012. Locations where mussels were deployed but no toxins were detected are indicated with an open circle.

Page 50

Top: Points represent samples of individual white sturgeon. Data from Davis et al. (2011) and others sources as compiled by the Water Board.

Bottom left: Lower left: Data from the RMP, 1997-2014. Bars represent averages; points represent individual samples.

Bottom right: Points represent average of composite samples (typically three composites per point).

Page 51

Total selenium concentrations

Map plot: Circles represent random sites. Diamonds represent historic fixed stations. Data from historic stations were excluded from the contour generation.

Trend plot: Individual points shown due to low sample sizes.

Page 54

Map plots: Circles represent random sites. Diamonds represent historic fixed stations. Data from historic stations were excluded from the contour generation.

Page 56

Average of Bay Area summer beach season (April-October) grades from Heal the Bay's annual beach report card (Heal the Bay 2014).

Page 57

Bay Area summer beach season (April-October) grades from Heal the Bay's annual beach report card (Heal the Bay 2014).

Page 58

Sum of PAH concentrations.

Map plots: Circles represent random sites. Diamonds represent historic fixed stations. Data from historic stations were excluded from the contour generation.

Page 59

Dissolved copper concentrations.

Map plot: Circles represent random sites. Diamonds represent historic fixed stations. Data from historic stations were excluded from the contour generation.

Page 60

The RMP measured water toxicity in 2002, 2007, and 2011. In 2011, water toxicity was measured at 22 stations distributed throughout the Bay. Most of the samples are collected at randomly selected locations, with a few fixed historic stations included to continue long-term time series. The test species was the mysid shrimp *Americamysis bahia*.

All fish contaminant data on a wet basis, unless otherwise noted.

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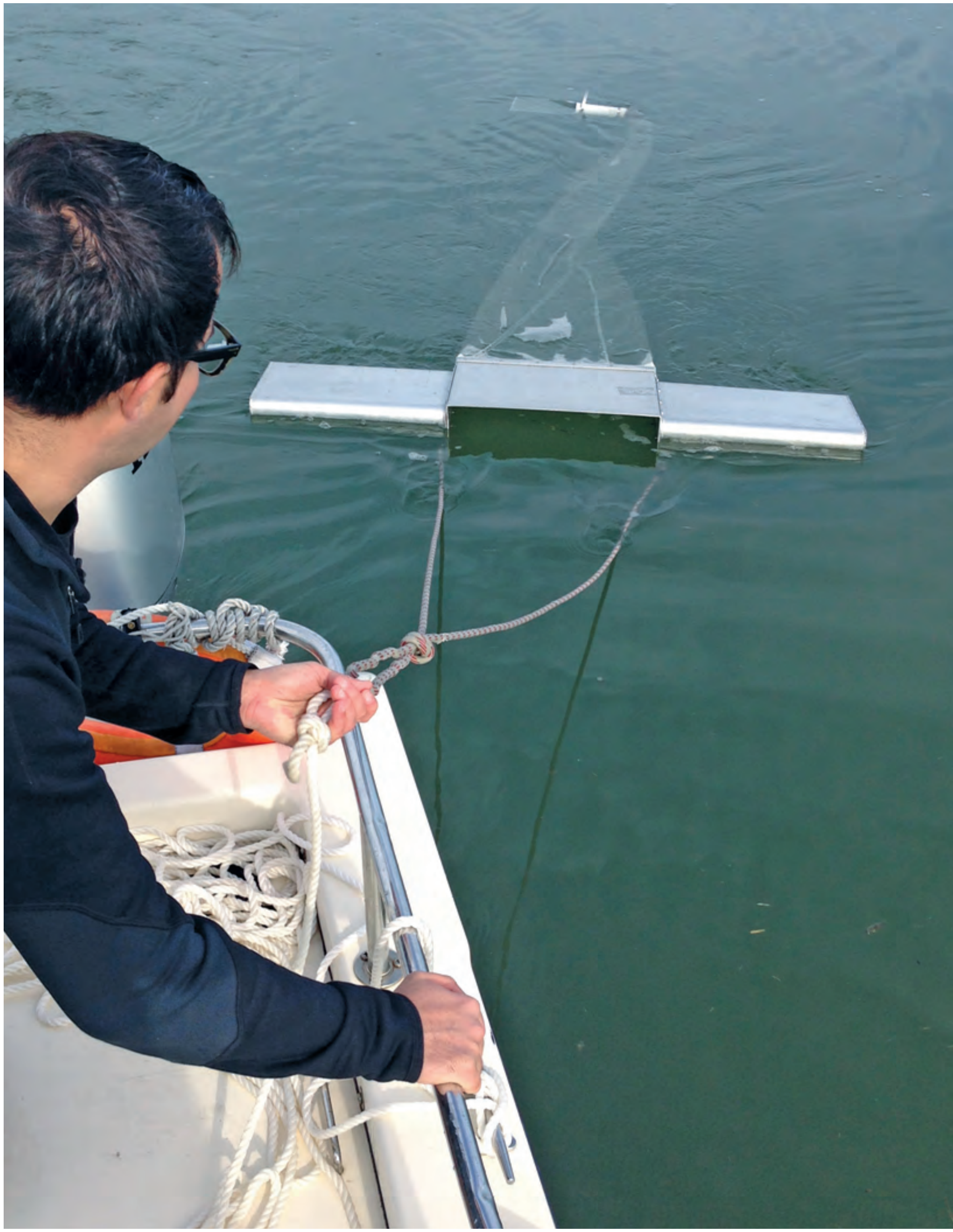

Sampling microplastics. Photograph by Meg Sedlak.

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Fairfield-Suisun Urban Runoff Management Program

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Mooring Road Neighborhood Association

Napa Yacht Club Homeowners Association

Phillips 66 Rodeo Terminal

Port of Oakland

Port of San Francisco

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US Army Corps of Engineers

US Coast Guard Environmental Division (Vallejo)

Valero Refining Company

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View from the Golden Gate Bridge. Photograph by Jay Davis.

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