

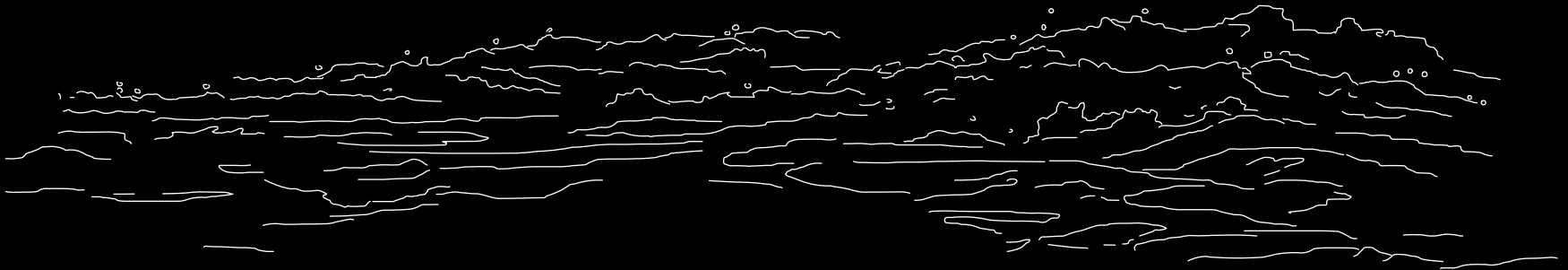
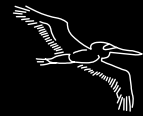
2006

# The Pulse of the Estuary

Monitoring and Managing Water Quality in the San Francisco Estuary

San Francisco Estuary Institute and the  
Regional Monitoring Program for Water Quality in the San Francisco Estuary

[www.sfei.org](http://www.sfei.org)



# The Pulse of the Estuary

Monitoring and Managing Water Quality in the San Francisco Estuary



## About This Report

*The Pulse of the Estuary* is the Annual Report of the Regional Monitoring Program for Water Quality in the San Francisco Estuary (RMP). The RMP is an innovative program providing the scientific foundation needed for managing water quality in a treasured aquatic ecosystem. The purpose of *The Pulse* is to make the most important information generated each year on water quality in the Estuary accessible to water quality managers, decision-makers, scientists, and the public.

*The Pulse* documents the extensive efforts made each year to manage and monitor water quality in the Estuary. A notable improvement this year is the achievement of a one-year turnaround from collection of RMP samples to reporting in *The Pulse*. This was accomplished through a concerted team effort of RMP staff and contractors. Due to this improved turnaround and a shift in the publication schedule, this *Pulse* reports two years worth of new monitoring results (from 2004 and 2005).

This *Pulse* describes many positive developments in managing and monitoring water quality in the Estuary. Cleanup plans (TMDLs) for mercury, PCBs, and selenium are in various stages of development and completion (page 6). A draft TMDL for PCBs is scheduled for release this fall, and will provide a focal point for tackling one of the Estuary's most persistent water quality problems (page 40). The TMDL will focus on reducing urban runoff loads, particularly in storm drain systems. A recent investigation in west Oakland provides an excellent demonstration of how environmental detective work in an urban watershed can represent the initial steps in the challenging task of finding cost-effective methods to reduce PCB loads from urban runoff to the Estuary (page 53).

The Water Board is developing new water quality objectives for cyanide, copper, and nickel (page 6). RMP data have shown that concentrations of these pollutants are generally below thresholds for concern in the Estuary. For example, a wealth of data on copper from the RMP and other sources has provided confidence that the water quality objective is rarely being exceeded (pages 24-25). Reduced loading of copper is considered to be one of the possible explanations for a surprising recent trend towards increased abundance of phytoplankton (page 62). Similarly, RMP data suggest that cyanide concentrations are below the threshold for concern, even though the existing standard is probably inappropriately low for this ecosystem. These examples demonstrate how RMP data help managers determine which pollutants are not a problem in the Estuary so that attention can be focused on the ones that are.

This issue of *The Pulse* also highlights some of the challenges currently being faced by water quality managers. Even though the activities that led to environmental contamination generally ceased long ago, mercury and PCBs are particularly formidable problems due to their widespread distribution in the watershed, persistence in the environment, and the way in which the Estuary traps contaminated sediment particles for many decades. For pollutants such as copper that are currently below thresholds of concern, continued management and monitoring is needed to ensure that concentrations remain low. Monitoring is also essential in identifying new pollutants of concern, several of which are highlighted in this issue. The use of pyrethroid insecticides has been increasing in recent years, and pyrethroid-induced toxicity in waters of the Bay-Delta has also been on the rise (page 71). Pyrethroids are highly toxic to fish, and are under consideration as one of the possible causes of the recent sharp decline in populations of several fish species (page 27). Other chemicals in current use, such as PBDEs (brominated flame retardants) and PFCs (fluorinated stain repellants and Teflon), are appearing in the water, sediment, and food web of the Estuary (pages 22 and 26).

*The Pulse of the Estuary* is one of three types of RMP reporting products. The second, the Annual Monitoring Results, is distributed via the SFEI web site ([www.sfei.org](http://www.sfei.org)) and includes comprehensive data tables and charts of the most recent monitoring results. The third product is the RMP Technical Reports series. RMP Technical Reports each address a particular RMP study or topic relating to contamination of the Estuary. A list of all RMP reports is available at [www.sfei.org](http://www.sfei.org).

Comments or questions regarding *The Pulse* or the Regional Monitoring Program can be addressed to Dr. Jay Davis, RMP Manager, (510) 746-7368, [jay@sfei.org](mailto:jay@sfei.org).

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For PDF versions of the 2003, 2004 and 2005 Pulses, please go to: [www.sfei.org/sfeireports.htm](http://www.sfei.org/sfeireports.htm)

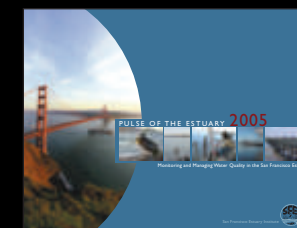
For more information about the San Francisco Estuary Institute and the RMP, please go to [www.sfei.org](http://www.sfei.org)



2003



2004



2005





### Recent developments in water quality management in the Estuary



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- 13 RMP Committee Members and RMP Participants

## Water Board Update on TMDLs and Water Quality Objectives

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<sup>1</sup> San Francisco Bay Regional Water Quality Control Board

### ★ Key Points

- The Water Board continues to make progress on several Bay TMDL and water quality objectives projects that rely heavily on information generated by the RMP
- The Water Board has revised the mercury TMDL to include reduced wasteload allocations for wastewater dischargers and new water quality objectives for large fish consumed by humans and small fish consumed by wildlife
- A proposed TMDL and implementation plan for PCBs anticipated for fall 2006 will focus on reducing urban runoff loads via source controls in zones of elevated PCBs in storm drains and interception or removal of PCBs in runoff or storm drain systems
- Plans are underway for developing a selenium TMDL and site-specific water quality objectives for cyanide and for copper and nickel in waters north of the Dumbarton Bridge



### Introduction

The San Francisco Regional Water Quality Control Board (Water Board) continues to make progress on several Bay TMDL and water quality objectives projects that rely heavily on past, current, and future RMP monitoring and special projects. These include TMDLs for mercury, PCBs, and selenium, and water quality objectives for mercury, copper, and nickel. An overview of these projects follows. In addition, projects to resolve Bay impairment by the legacy pesticides DDT, chlordane, and dieldrin, and impairment of Suisun Marsh by low dissolved oxygen and mercury will begin during the coming year. During the past year, the Water Board completed TMDLs for diazinon and pesticide-related toxicity in urban creeks and for pathogens in Napa River and Sonoma Creek; TMDLs for mercury in the Guadalupe River Watershed and sediment in Napa River are nearly completed. Information on these TMDLs and all TMDL projects is available on the Water Board website at <http://www.swrcb.ca.gov/rwqcb2/tmdlmain.htm>.

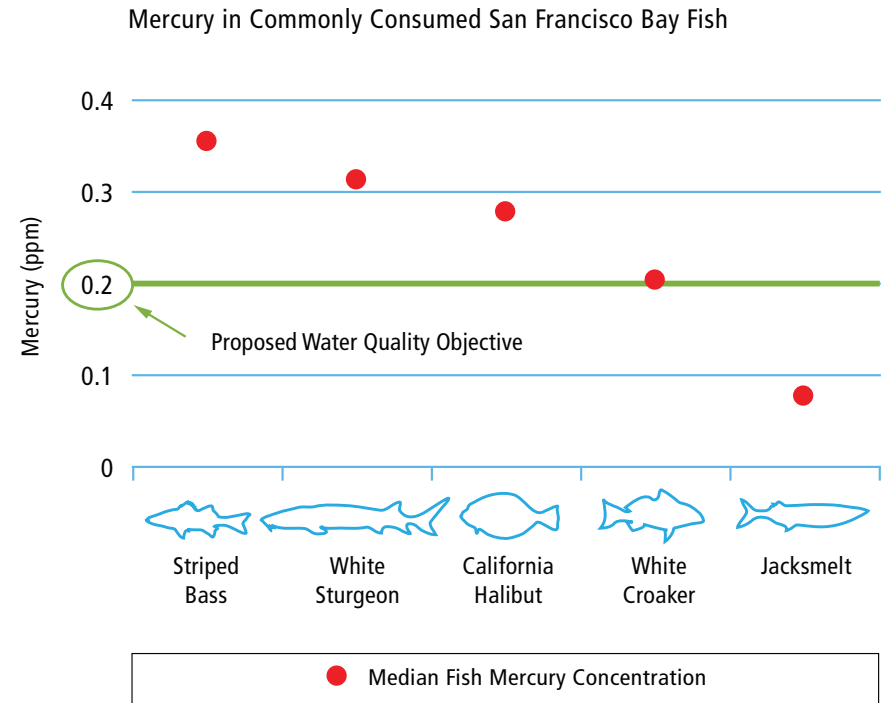
## Mercury

Excessive amounts of mercury found in San Francisco Bay fish and other aquatic organisms make Bay fish unhealthy for consumption by both humans and wildlife. The Water Board adopted a TMDL for mercury in the Bay in 2004 to restore these beneficial uses. Overall, the TMDL is designed to control sources of total mercury entering the Bay while advancing understanding of sources, production, fate, and transport of methylmercury, the form of mercury that accumulates in the food web and poses health risks to humans and wildlife. Subsequently, however, the State Water Resources Control Board remanded the TMDL back to the Water Board to resolve concerns with several issues including wasteload allocations for wastewater dischargers and attainment of the water quality objective for mercury in Bay waters.

The Water Board has now revised the TMDL in response to the State Water Board remand. A key revision is a reduction to the wasteload allocations for wastewater dischargers by nearly half. The Water Board is also replacing the outdated water quality objective for mercury in Bay waters with two new water quality objectives, 0.2 mg/kg in large fish that humans consume (Figure 1), and 0.03 mg/kg in smaller fish consumed by birds.

For several years, the RMP has played a key role in monitoring for total and methylmercury in large fish, water, and sediment. Now the Water Board will also call on the RMP to monitor for mercury in small fish. In response to this need, the RMP initiated a pilot study in 2005 examining mercury in small fish (see page 18). The RMP is also collaborating with the Clean Estuary Partnership to characterize mercury in buried sediment throughout the Bay and to develop a robust mercury mass balance model. In addition, the RMP will likely be involved in the evaluation of methylmercury in the Bay and potential local effects.

For several years, the RMP has played a key role in monitoring total and methylmercury in fish, water, and sediment



Footnote: RMP data from 2003

**Figure 1. Mercury in commonly consumed fish from San Francisco Bay.** The Water Board is replacing the outdated water quality objective for mercury in Bay waters with two new water quality objectives: 0.2 ppm in large fish that humans consume, and 0.03 ppm in smaller fish consumed by birds. Several popular sport fish species have median concentrations greater than the 0.2 ppm objective.

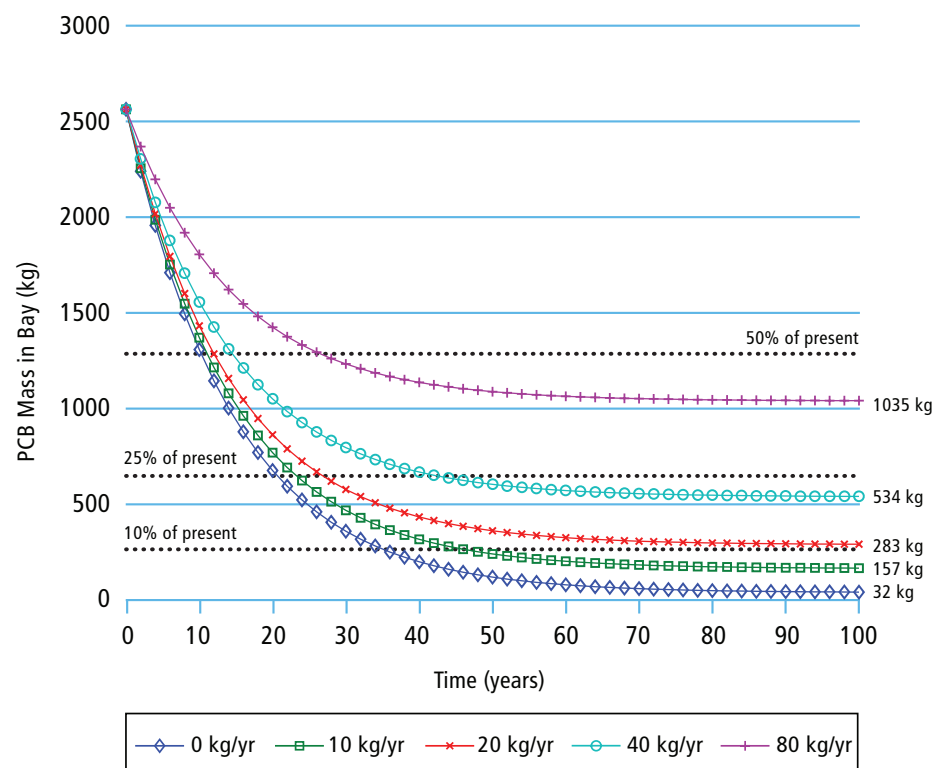
## PCBs

The Water Board plans to release a proposed PCBs TMDL and implementation plan in the fall of 2006

Levels of polychlorinated biphenyls (PCBs) in San Francisco Bay fish also threaten human health and the survival of Bay wildlife. Although use of PCBs is now tightly regulated, they have accumulated over the years in Bay sediments and are still found throughout urban areas. Areas of elevated PCBs in Bay sediments and in industrial areas around the Bay are of particular concern.

The Water Board plans to release a proposed PCBs TMDL and implementation plan in the fall of 2006. The TMDL is designed to attain a numeric target of 10 ppb in white croaker. This target is protective of both human health and wildlife. In the most recent RMP sampling, PCB concentrations in white croaker ranged from 239 to 530 ppb and averaged 342 ppb. The proposed maximum load is 270 grams per day (or 10 kg/year). This is based on linkage analysis performed using two models developed via support by the RMP: a food-web PCB bioaccumulation model and a long-term fate mass balance model. Both models treat all Bay segments as a single unit. The models predict that attainment of the numeric targets will occur when in-Bay sediment PCB concentrations decline to 1 ppb and external loads are reduced to 10 kg/yr (Figure 2).

The proposed implementation plan will focus on reducing urban runoff loads via source controls in storm drains in older industrial areas and strategic opportunities to intercept or remove PCBs in runoff or storm drain systems, such as routing contaminated runoff to wastewater treatment systems where possible. The TMDL will rely on on-going monitoring by the RMP for PCBs in Bay sediments and fish. It also calls for special studies to resolve key uncertainties including the rate of degradation of PCBs in the environment, and the presence and fate of PCBs in buried sediment throughout the Bay. The RMP is collaborating with the Clean Estuary Partnership to characterize PCBs in buried sediment throughout the Bay and to develop a more robust mass balance model. A Prop 13-funded project led by the San Francisco Estuary Institute is also underway to evaluate methods for reducing sediment-associated pollutants, including PCBs, in urban runoff.



**Figure 2. Predicted declines in the mass of PCBs in the Bay under different loading scenarios.** The proposed maximum load is 270 grams per day (or 10 kg/year). This is based on linkage analysis performed using two models developed via support by the RMP: a food-web PCB bioaccumulation model and a long-term fate mass balance model. Both models treat all Bay segments as a single unit. The models predict that attainment of the numeric targets will occur when in-Bay sediment PCB concentrations decline to 1 ppb and external loads are reduced to 10 kg/yr.



## Selenium

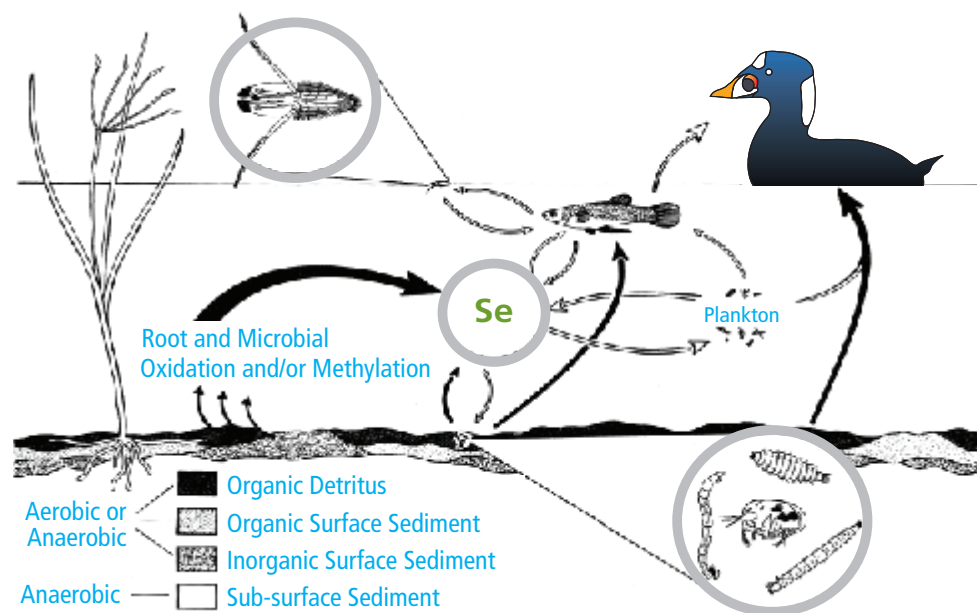
The Bay is listed as impaired by selenium because bioaccumulation of this element has led to a health advisory for local hunters who eat diving ducks from the Bay, and also because of potential reproductive impacts to ducks and other wildlife. The selenium problem seems to have been exacerbated by the introduction of the Asian clam (*Corbula amurensis*) in to the Bay in 1986. This non-native clam is a prodigious filter feeder. By consuming large quantities of selenium-laden particles, it has moved a considerable mass of selenium into the benthic food web and thus to diving ducks and large fish such as sturgeon. There is also a concern that selenium may be causing deformities in Sacramento splittail.

**The Water Board is developing a project plan in conjunction with the Clean Estuary Partnership for a selenium TMDL**

The Water Board is developing a project plan in conjunction with the Clean Estuary Partnership for a San Francisco Bay selenium TMDL. Potential analyses include:

- Development of numeric targets consistent with USEPA and state efforts to establish water quality objectives for selenium in fish;
- Evaluation of wastewater and urban runoff selenium loads and potential control actions;
- Evaluation of implications for the Bay of ongoing and anticipated actions to control selenium sources in the Central Valley; and
- Identification of an apparent source of selenium in the South Bay and potential control actions.

A key effort will be to increase understanding of the fate and transport of selenium by refining both a food web model and a mass balance model that will link specific sources to the selenium impairment. Existing RMP monitoring of selenium in Bay water, sediment, and fish will be used in both development and implementation of the TMDL (Figure 3). The selenium TMDL is expected to culminate with Water Board hearings in early 2009.



**Figure 3. Selenium pathways through the food web.** The Bay is listed as impaired by selenium because bioaccumulation of this element has led to a health advisory for local hunters who eat diving ducks from the Bay, and also because of potential reproductive impacts to ducks and other wildlife in the Estuary. A key effort in developing a TMDL for selenium will be to increase our understanding of the fate and transport of selenium by refining both a food web model and a mass balance model that will link specific sources to the selenium impairment.



## Cyanide

The Water Board is working to establish new site-specific marine water quality objectives for cyanide in water: 2.9 µg/L as a 4-day average and 9.4 µg/L as a 1-hour average. These objectives better reflect current understanding of cyanide toxicity and its effects on aquatic organisms specific to the Bay. This is important because the California Toxics Rule marine acute and chronic criteria that currently apply, derived in 1985, were driven by toxicity data for the eastern rock crab (*Cancer irroratus*), a species not found on the West Coast. The new cyanide objectives will reflect the most recent toxicity data for several species of crabs common to San Francisco Bay and Puget Sound, where the new criteria have already been adopted by the State of Washington.

Cyanide is commonly found in treated industrial and municipal wastewaters due in part to chlorine disinfection prior to discharge to the Bay. However, not all forms of cyanide are toxic, and cyanide degrades rapidly in marine waters. RMP monitoring confirms that ambient cyanide concentrations in the water column of San Francisco Bay are consistently low and do not exceed 0.4 µg/L. Hearings on a Basin Plan amendment that will establish the new cyanide objectives are planned for the fall of 2006.

## The Clean Water Act and TMDLs


The Clean Water Act (CWA) recognizes that every body of water provides benefits that are valuable and worth protecting. The designated “beneficial uses” of a bay, lake, river, stream, or coastline determine the level of water quality protection the water body needs to keep it healthy. Some of San Francisco Bay’s beneficial uses are fish migration and spawning, wildlife habitat, fishing, swimming, and boating, as well as navigation and support for industrial processes.

A water body that is polluted and does not support its uses is “impaired” under the terms of the CWA. Each state is required to develop a list of impaired waters and the contaminants that impair them (the “303(d) List” – see page 12). Then, for each impaired waterbody, the state must prepare a comprehensive, science-based cleanup plan, known as a water quality attainment strategy or “total maximum daily load” (TMDL). A TMDL sets goals (“targets”) for safe levels of the pollutant under study, and allocates pollutant discharge amounts among identified dischargers. After adoption by the Water Board and approval by the State Water Board and the federal Environmental Protection Agency, the TMDL becomes part of the official Water Quality Control Plan (“Basin Plan”) for the region.

## Copper and Nickel

The Water Board is developing site-specific water quality objectives for copper and nickel that will apply to all Bay segments north of the Dumbarton Bridge. These metals are known to be toxic to aquatic life, especially juvenile stages of shellfish. In the Bay, these two metals have been suspected since the early 1990s of impairing aquatic life. Water quality objectives for copper and nickel, based on the dissolved forms of the metals, were adopted in 2001 by USEPA via the California Toxics Rule, and provide for site-specific adjustments.

This project is using the same approach used by the Water Board when it adopted site-specific objectives for these metals in the South Bay south of the Dumbarton Bridge in 2004. It was learned that the chemical characteristics of San Francisco Bay reduce the toxicity of copper and nickel because these metals are bound by a variety of dissolved compounds and rendered less toxic to aquatic life. Thus the water quality objectives for copper and nickel could be raised while still protecting beneficial uses. The approach includes copper toxicity testing on sensitive species and updating the list of species used to compute the objectives for nickel.

It is important to note that concentrations of both copper and nickel in the Bay are below the site-specific objectives and we are now confident that beneficial uses are not adversely impacted. However, ambient concentrations of copper in sediments and water are not far below levels of concern. Therefore, it is important to guard against future increased concentrations in the Bay; a particular challenge because some of the largest sources, like copper from vehicle brake pads, may increase as population increases. A critical component of this project is development of a management strategy that ensures that future increases in copper and nickel concentrations will not occur. The strategy will include actions to control known sources in wastewater, urban runoff, and use of copper in shoreline lagoons and on boats. More aggressive actions to control sources can be triggered by increases in copper or nickel concentrations in the Bay, so RMP monitoring of copper and nickel will be a vital component of the management strategy. Water Board hearings on the proposed copper and nickel water quality objectives are expected this winter. 

## Regulatory Sediment Quality Objectives (SQOs) for California Bays and Estuaries

The State Water Resources Control Board (State Water Board) has been developing SQOs for California Bays and Estuaries since 2003. The new SQOs will be the first ever established for California water bodies, intended for use in assessing whether beneficial uses are protected, at risk, or degraded. SFEI staff has participated as part of the SQO Science Team along with scientists from the Southern California Coastal Water Research Project and Moss Landing Marine Laboratory. The Science Team is developing appropriate tools to assess the risk posed to sediment-dwelling organisms directly exposed to pollutants in sediment and the risk posed to humans and wildlife by pollutants that enter the food chain from contaminated sediments.

Sediment quality is very complex and the Science Team is developing an approach that has not previously been applied within a regulatory program. The proposed SQOs will not be traditional individual contaminant threshold values, but will use multiple lines of evidence in support of narrative objectives. The lines of evidence will include measurements of exposure (contaminant concentrations), and biological effects (toxicity and benthic community composition) for aquatic life assessments. In developing the SQOs, a large database of sediment information from previous studies in California bays and estuaries was compiled. The current efforts have focused on two types of bays with sufficient data available: San Francisco Bay and high salinity bays in southern California. Assessment methods are focused primarily on assessing a site or sample, but multiple sites within a region may also produce a "water body" assessment. Data from a sample, for each line of evidence, are placed in one of several categories of degree of exposure or effects, and the three lines of evidence are integrated into an overall site assessment based on a set of thresholds, rules, and definitions.

The fish and wildlife assessment procedures are not as well developed as those for aquatic life because there are much fewer data. Current efforts have focused on case studies in Newport Bay and San Francisco Bay. The lines of evidence used are fish tissue contaminant concentrations, sediment contaminant exposure, and laboratory bioaccumulation studies.

The institutional process for SQO development includes the Science Team, a National Scientific Steering Committee, an Advisory Committee composed of stakeholders, and an Agency Coordination Committee. The State Water Board plans to circulate the draft objectives and policy in August of this year. However, the proposed SQOs for aquatic life in Bays will not be adopted until 2008. At the same time, similar efforts are being planned for developing SQOs for bays with lower salinities and for the Delta. These efforts will require additional field sampling and analysis before a habitat-specific assessment framework can be developed, with SQOs for those regions to be completed by 2010.

Contact: Bruce Thompson, San Francisco Estuary Institute, [bruce@sfei.org](mailto:bruce@sfei.org)

## A Contamination Index for San Francisco Estuary

The San Francisco Estuary Project identified twelve indices needed to assess the condition of the San Francisco Estuary (Thompson and Gunther 2004, TBI 2003). One of the twelve indices is a Contamination Index. SFEI has been developing a Contamination Index that includes indicators of water and sediment contamination, the incidence of toxicity, aquatic life impacts, and fish tissue bioaccumulation. While the sediment contamination index being developed for the State's Sediment Quality Objectives (SQO) program can be easily adapted for use in the Contamination Index, there is also a need for a water contamination index. Therefore, a Water Contamination Index (WCI) is being developed using an assessment framework similar to that used for developing SQOs.

The proposed WCI is described in a draft report to SFEP (Thompson *et al.* 2006). It includes three lines of evidence: water contamination (exposure indicator), aquatic toxicity, and other biological effects. RMP data were used to establish several categories of water exposure and toxic effects. Since there have been no studies that link water contamination with impacts on plankton or fish communities (analogous to using benthic communities in the SQO assessment), biological effects thresholds from the scientific literature will be used. The three lines of evidence will be used together to create the WCI using similar rules and definitions as proposed for the SQO assessment. The WCI is intended for assessment of aquatic life impacts, not for assessing human health impacts from fish consumption or water exposure. Those impacts will be addressed by a separate part of the overall SFEP index scheme.

There are numerous details and decisions to be made in developing the WCI that need to be fully reviewed, discussed, and vetted among Estuary managers, stakeholders, and scientists. The Draft WCI currently in review is intended as a concept for further development, and will no doubt be modified as a result of the review process.

Contact: Bruce Thompson, San Francisco Estuary Institute, [bruce@sfei.org](mailto:bruce@sfei.org)

## The 303(d) List and the San Francisco Estuary

Under Section 303(d) of the 1972 Clean Water Act, the State Water Resources Control Board (State Water Board) is required to compile a list of water bodies that exceed water quality standards, referred to as the 303(d) List. The State Water Board is further required to develop cleanup plans known as Total Maximum Daily Loads (TMDLs) for each pollutant listed on the 303(d) List. The RMP is one of several organizations that provide scientific data to the State Water Board to compile the 303(d) List and to develop TMDLs.

The State Water Board most recently compiled a 303(d) List for the State in February 2003. This List was revised and approved by USEPA in July 2003. The primary pollutants/stressors for the Estuary and its major tributaries on the 303(d) List include:

**Trace elements:** Mercury, Nickel, and Selenium

**Pesticides:** Chlordane, DDT, Diazinon, and Dieldrin

**Other chlorinated compounds:** PCBs, Dioxin and Furan Compounds

**Others:** Exotic species, Nutrients, and Pathogens

Mercury and PCBs have been designated as a high priority for developing TMDLs. A San Francisco Bay mercury TMDL was adopted by the San Francisco Bay Regional Water Quality Control Board (Water Board) in September 2004. In response to a remand by the State Water Board issued in September 2005, the Water Board has now revised the TMDL. Key revisions include reduced waste-load allocations for wastewater dischargers and new water quality objectives for mercury in fish tissue. Release of a proposed PCBs TMDL and implementation plan is anticipated in the fall of 2006. A TMDL for selenium is in the initial stages of planning.

The State Water Board is expected to complete an updated 303(d) List this fall. Delisting of all bay segments for diazinon is proposed. Additional listings for various chemicals in Bay margin sites (e.g., Castro Cove, Central Basin, Islais Creek, Oakland Inner Harbor and San Leandro Bay) are proposed.

**For more information on the 303(d) List and TMDLs, see the following web sites:**

**303(d) List for Region 2 (which includes the Estuary):**

→ [www.waterboards.ca.gov/sanfranciscobay/TMDL/303dlist.htm](http://www.waterboards.ca.gov/sanfranciscobay/TMDL/303dlist.htm)

**TMDLs:**

→ [www.waterboards.ca.gov/sanfranciscobay/tmdlmain.htm](http://www.waterboards.ca.gov/sanfranciscobay/tmdlmain.htm)

→ [www.epa.gov/owow/tmdl/](http://www.epa.gov/owow/tmdl/)

**Mercury TMDL:**

→ [www.waterboards.ca.gov/sanfranciscobay/TMDL/sfbaymercurytmdl.htm](http://www.waterboards.ca.gov/sanfranciscobay/TMDL/sfbaymercurytmdl.htm)



## RMP Committee Members and RMP Participants

### RMP Committee Members

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POTWs, Francois Rodigari, East Bay Municipal Utilities District  
South Bay Dischargers, Tom Hall, EOA Inc.

Refineries, Bridgette DeShields, Blasland, Bouck and Lee, Inc.

Industry, Dave Allen, USS-POSCO

Stormwater Agencies, Chris Sommers, EOA, Inc.

Dredgers, John Prall, Port of Oakland

San Francisco Bay Regional Water Quality Control Board, Karen Taberski

U.S. EPA, Luisa Valiela

City of San Jose, **David Tucker**

City/County of San Francisco, Michael Kellogg

U.S. Army Corps of Engineers, Robert Lawrence

#### RMP Technical Review Committee Chair in bold print

#### RMP Steering Committee

Small POTWs, Ken Kaufman, South Bayside System Authority

Medium-sized POTWs, Daniel Tafolla, Vallejo Sanitation and Flood Control District

Large POTWs/BACWA, Chuck Weir, East Bay Dischargers Authority

Refineries, **Kevin Buchan**, Western States Petroleum Association

Industry, Dave Allen, USS-POSCO  
Cooling Water, Steve Bauman, Mirant of California

Stormwater Agencies, Adam Olivieri, EOA, Inc.

Dredgers, Ellen Johnck, Bay Planning Coalition

San Francisco Bay Regional Water Quality Control Board, Dyan Whyte

#### RMP Steering Committee Chair in bold print

### RMP Participants

#### Municipal Dischargers

Burlingame Waste Water Treatment Plant

Central Contra Costa Sanitary District

Central Marin Sanitation Agency

City of Benicia

City of Calistoga

City of Palo Alto

City of Petaluma

City of Pinole/Hercules

City of Saint Helena

City and County of San Francisco

City of San Jose/Santa Clara

City of San Mateo

City of South San Francisco/  
San Bruno

City of Sunnyvale

Delta Diablo Sanitation District

East Bay Dischargers Authority

East Bay Municipal Utility District

Fairfield-Suisun Sewer District

Las Gallinas Valley Sanitation District

Marin County Sanitary District #5, Tiburon

Millbrae Waste Water Treatment Plant

Mountain View Sanitary District

Napa Sanitation District

Novato Sanitation District

Rodeo Sanitary District

San Francisco International Airport

Sausalito/Marin City Sanitation District

Sewerage Agency of Southern Marin

Sonoma County Water Agency

South Bayside System Authority  
Town of Yountville

Union Sanitary District

Vallejo Sanitation and Flood Control District

West County Agency

#### Industrial Dischargers

C & H Sugar Company

Chevron Products Company

Crockett Cogeneration

Dow Chemical Company

General Chemical Corporation

TOSCO – Rodeo Refinery

Rhodia, Inc.

Shell – Martinez Refining Company

Tesoro Golden Eagle Refinery

USS – POSCO Industries

Valero Refining Company

#### Cooling Water

Mirant of California

### Stormwater

Alameda Countywide Clean Water Program

Caltrans

City and County of San Francisco

Contra Costa Clean Water Program

Fairfield-Suisun Urban Runoff Management Program

Marin County Stormwater Pollution Prevention Program

San Mateo Countywide Stormwater Pollution Prevention Program

Santa Clara Valley Urban Runoff Pollution

Vallejo Sanitation and Flood Control District

### Dredgers

Ballena Bay Townhouse Association

Benicia Port Terminal Company, Pier 95

Boy Scouts of America, Marin Council

Caltrans Bay Bridge, East Span

Caltrans Benicia-Martinez Bridge Retrofit & New

Chevron Richmond Long Wharf

City of Benicia Marina

City of Emeryville Marina

City of San Rafael, San Rafael Creek Berths

City of Vallejo Ferry Terminal

City of Vallejo Marina

Conoco Phillips

County of Marin, Park District, Black Point Boat Ramp

Coyote Point Marina

Marin County Service Area 29, Paradise Cay

Marina Plaza Harbor

Marina Vista Homeowners Association

Oyster Cove Marina

Port of Oakland

Port of Redwood City

Port of San Francisco

Ryer Island Boat Harbor

San Francisco Drydock

San Rafael Rock Quarry

Shoonmaker Point Marina

U.S. Army Corps of Engineers

Mare Island

Valero Refining Co.





## Status and Trends Update



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- 29 Water Quality Trends at a Glance

## The Latest Monitoring Results

★ Findings from RMP Monitoring and Other Bay Studies

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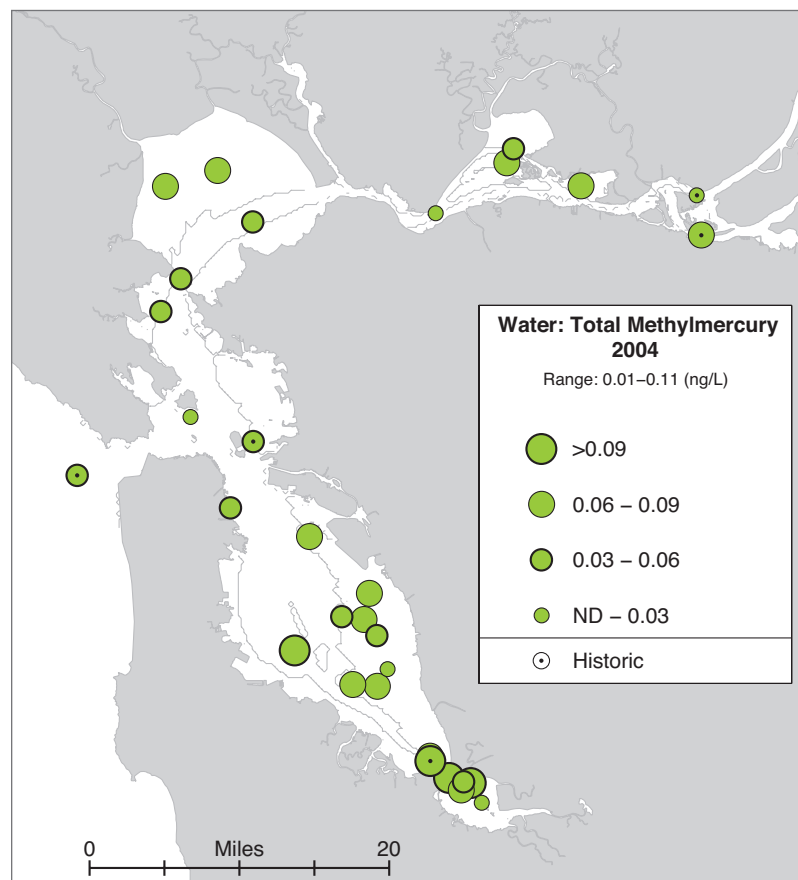
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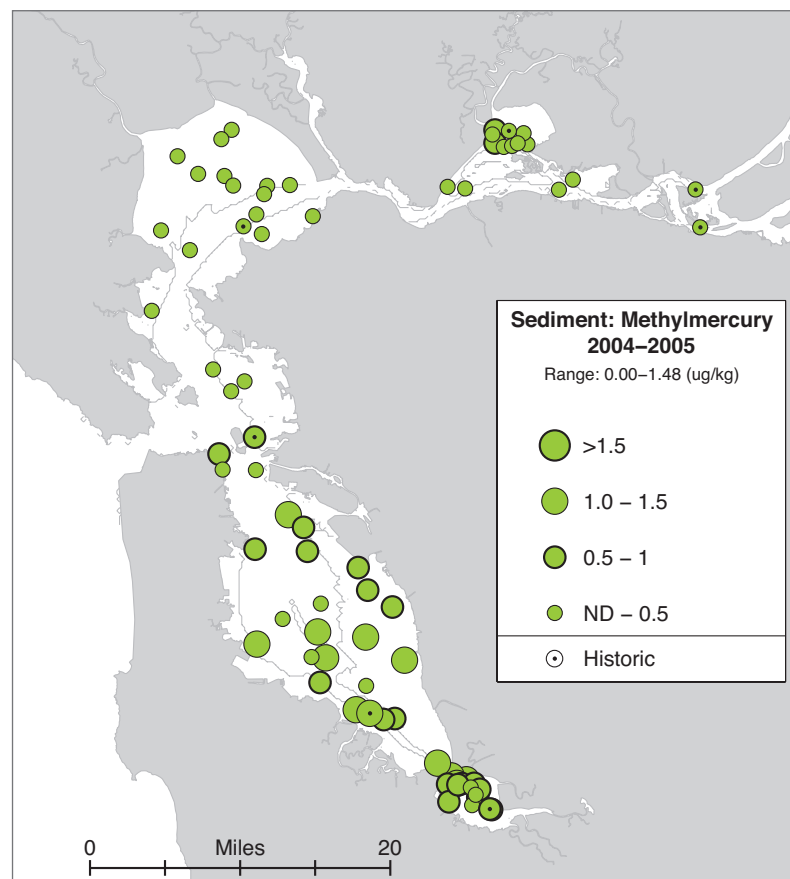


## → Mercury

Mercury contamination is one of the top water quality concerns in the Estuary and mercury clean-up is a high priority of the Water Board. Mercury is a problem because it accumulates to high concentrations in some fish and wildlife species. The greatest health risks from mercury are faced by humans and wildlife that consume fish.



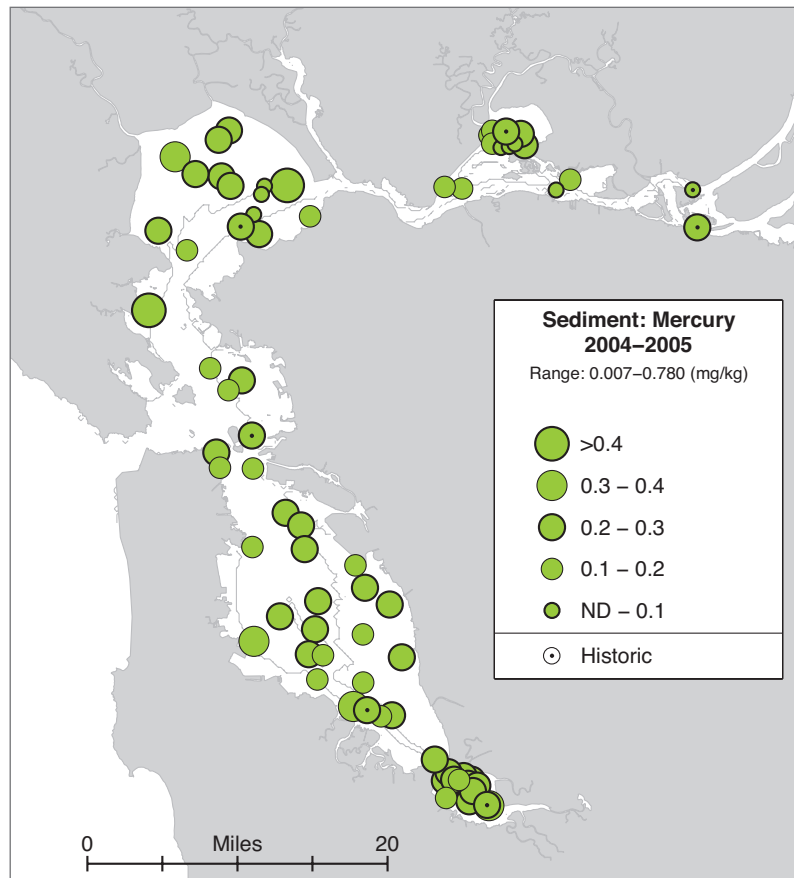
Footnote: 2005 data not available at time of printing due to analytical problems.



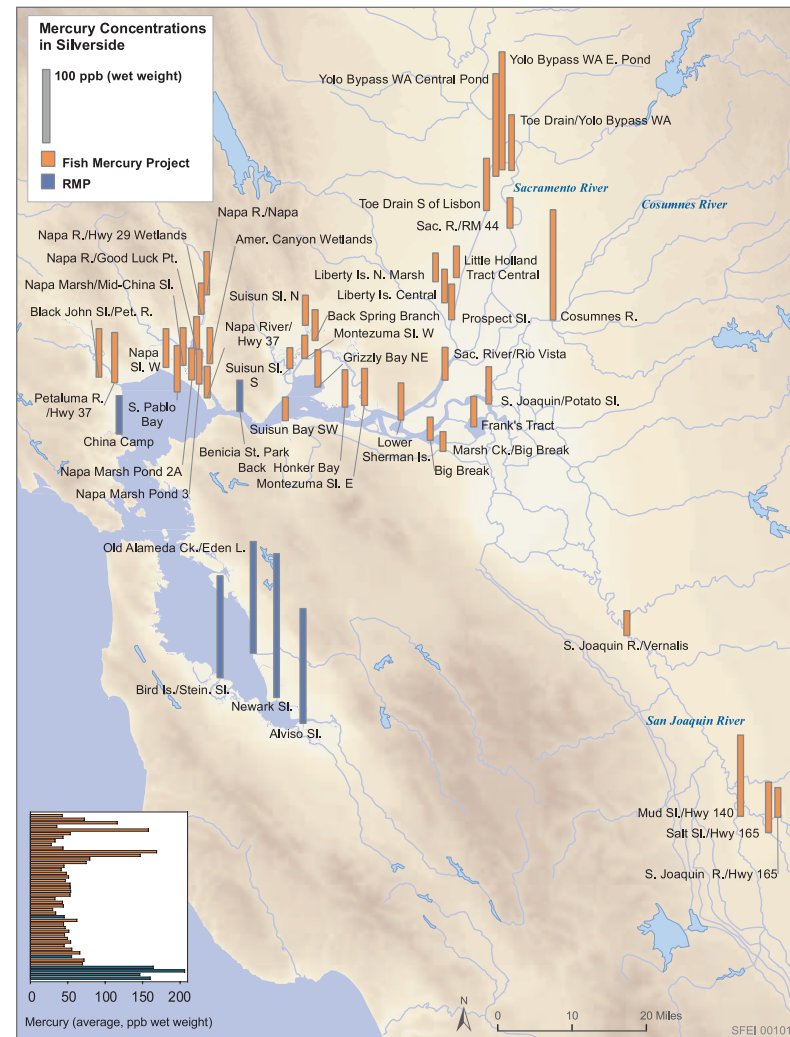
■ **Methylmercury in water, 2004.** Mercury exists in many different forms in the aquatic environment. Methylmercury is the form that is readily accumulated in the food web and poses a toxicological threat to highly exposed species. Methylmercury has a complex cycle, influenced by many processes that are variable in space and time. In the past few years the RMP has begun measuring methylmercury in water and sediment of the Bay in order to better understand the sources of the methylmercury that is accumulated by Bay fish and wildlife. Three of the five highest values measured in 2004 were from Lower South Bay. However, the ranges of concentrations in each segment were fairly similar.

■ **Methylmercury in sediment, 2004 and 2005.** Mercury is converted to methylmercury primarily by bacteria in sediment. Methylmercury production can vary tremendously over small distances and over short time periods, so this figure should be considered a snapshot of conditions in the Bay at the times of these surveys in the summers of 2004 and 2005. Concentrations from the Bay Bridge south were consistently higher than those in the northern Estuary. No regulatory guideline exists for methylmercury in sediment.

## → Mercury continued



→  
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RMP Study – Ben Greenfield, [ben@sfei.org](mailto:ben@sfei.org)



Footnote: Inset shows bars on a common scale for direct comparison.

■ **Total mercury in sediment, 2004 and 2005.** In 2004 and 2005, 58 of 94 (62%) of Bay sediment samples had concentrations higher than 0.2 mg/kg. Most samples (54%) were between 0.2 and 0.3 mg/kg. A site near Mare Island in San Pablo Bay had the highest concentration of 0.78 mg/kg.

■ ↑ **Small fish monitoring reveals high mercury exposure in the South Bay.** Small fish are an excellent indicator of fine-scale spatial and temporal patterns in mercury and wildlife exposure to mercury in aquatic ecosystems. Two studies in 2005 combined to provide a thorough coverage of the Estuary. In the larger of the two studies, Darell Slotton and colleagues at U.C. Davis have sampled several species of small fish throughout the north Bay, Delta, and Central Valley in an effort to evaluate the local and regional impacts of habitat restoration on mercury in the food web.

continued >

## → Mercury continued

The most widespread species they sampled is the inland silverside (*Menidia beryllina*), which has proven to be a particularly effective mercury indicator for the Estuary. The extensive silverside sampling by U.C. Davis in 2005 (orange bars) identified three areas – the Cosumnes River, the Yolo Bypass, and Mud Slough – with particularly high average concentrations (from 116 to 169 ppb). Concentrations at other locations across the Estuary were consistently in the range of 50 ppb.

A second smaller study to sample mercury in small fish in the Estuary in 2005 was conducted by the RMP (blue bars). Silverside were sampled at six locations, including four in the South Bay and two in the North Bay. Results for the North Bay were consistent with the U.C. Davis data for North Bay. In the South Bay, however, concentrations were higher than in any other part of the Estuary, with a maximum of 206 ppb at Newark Slough. These findings are consistent with sport fish and bird egg data indicating high concentrations of mercury in the South Bay food web, and with higher methylmercury concentrations measured in South Bay sediments. Small fish monitoring will be a valuable tool for evaluating whether habitat restoration in the Bay-Delta exacerbates the existing mercury problem.

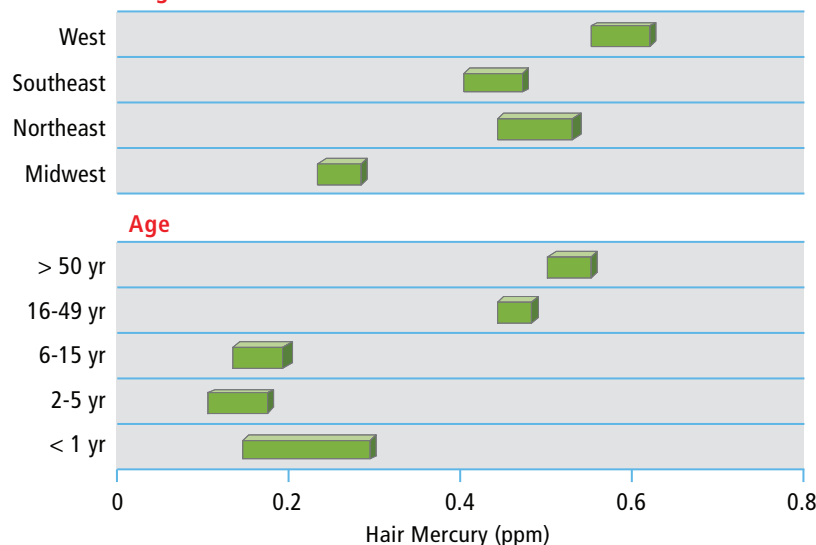
➔ **National Hair Mercury Survey Shows Regional Patterns.** The driving factor for the mercury TMDL is the concern that people, particularly pregnant women and young children, who eat contaminated fish will suffer from the neurotoxic effects associated with mercury. USEPA (<http://www.epa.gov/NCEA/pdfs/methmerc.pdf>) has calculated estimated safe levels of exposure for the human population, including sensitive subgroups, based on three epidemiological studies in the Seychelles Islands, Faroe Islands, and New Zealand. While the Seychelles study has yielded no evidence of impairment, the two other studies do show dose-related effects of mercury, and USEPA used the bigger Faroe study to set safe levels.

Mercury can be easily measured in a strand of hair, providing a valuable indicator of human exposure. EPA used the thresholds determined from the epidemiological studies with a safety margin of a factor of ten to calculate the safe dosage ("Reference Dose") that the Water Board used in setting a fish target of 0.2 ppm. The hair concentration corresponding to this Reference Dose is 1 ppm.

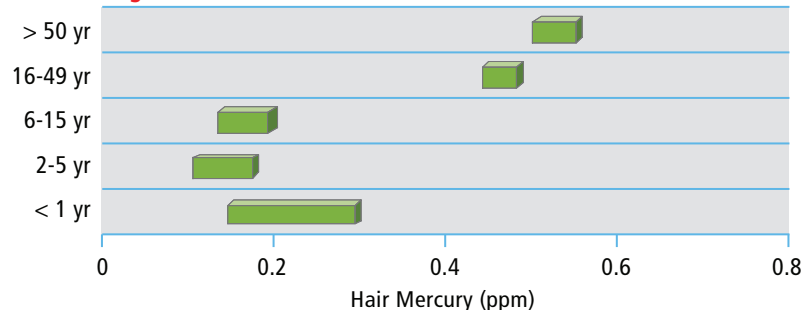
Hair monitoring makes it possible to compare the status of human mercury exposure in the Bay Area to other parts of the country. The most recent ongoing survey is being conducted by several environmental groups and the University of North Carolina at Asheville (UNCA). The UNCA data must be interpreted cautiously because the samples come from self-selected volunteers and hair can be contaminated by dust or hair products. However, this sample collection is the largest in the US (6583 participants), and its results are consistent with other national surveys. The UNCA study shows that hair mercury concentrations depend on gender, race, fish consumption, and residence. The highest concentrations are found in people living in large coastal cities. The highest concentrations were found in New York City residents (median 0.88 ppm Hg; 47% > 1 ppm). In San Francisco residents median mercury concentrations were 0.68 ppm, with 29.5% > 1 ppm.

### Human Mercury Exposure Depends On Region, Age, Consumption Rate, Race, and Gender

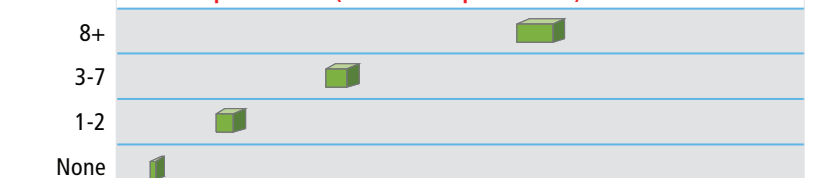
#### Region



#### Age



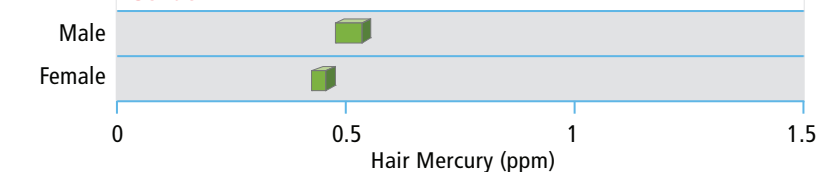
#### Consumption Rate (Fish meals per month)



#### Race



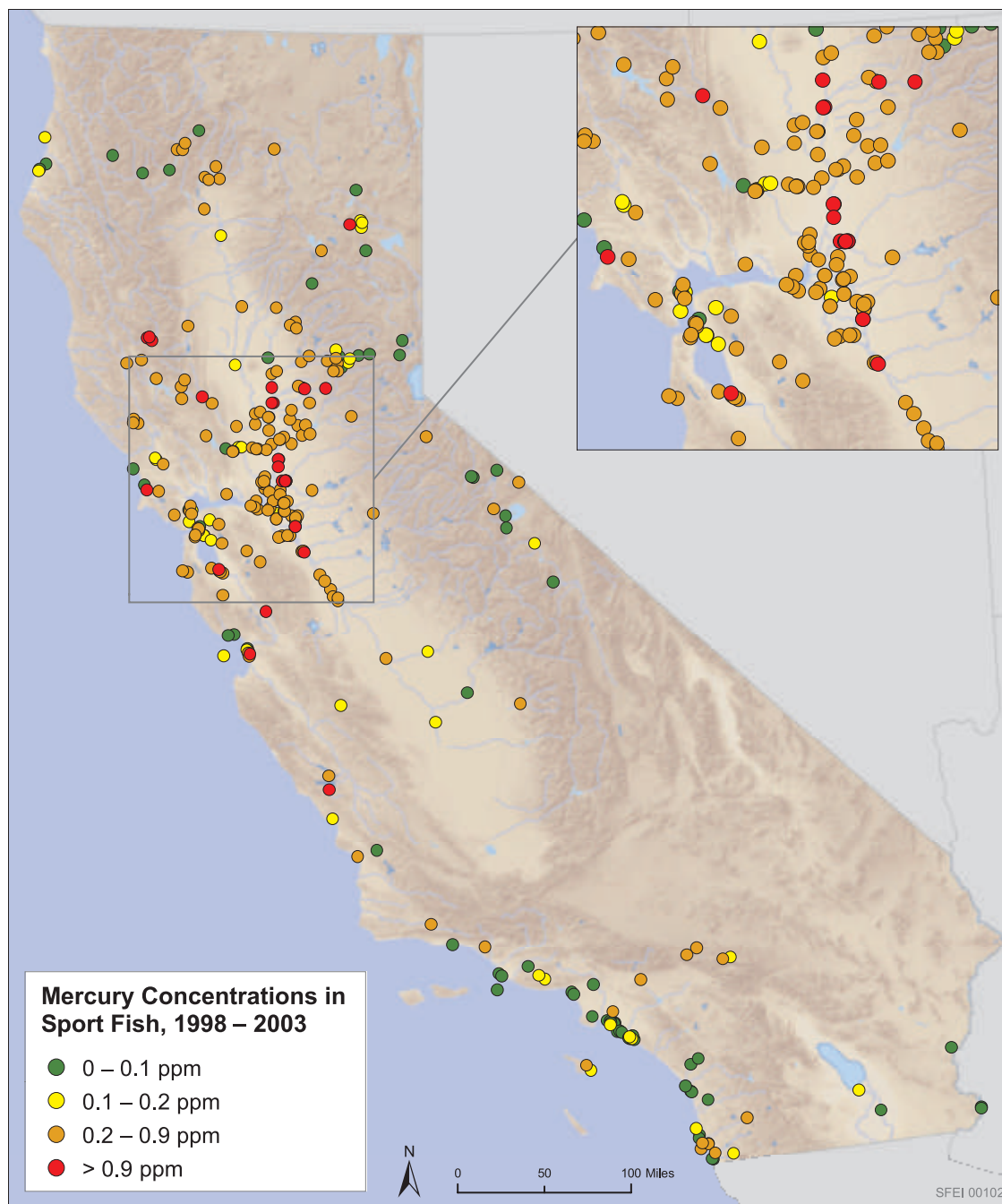
#### Gender



Footnote: Data from (<http://orgs.unca.edu/eqi/MercHairTechRep11-05.pdf>)

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San Francisco Estuary Institute,  
[mikec@sfei.org](mailto:mikec@sfei.org)

## → Mercury continued



Footnote: Based on mercury measurements in edible tissue from a variety of sport fish species from 1998 – 2003. Size limits for each species were applied. Dots represent sampling locations.

Reference: Davis, J.A., J.L. Grenier, A.R. Melwani, S. Bezalel, E. Letteney, E. Zhang. 2006. Draft Report: The Impact of Pollutant Bioaccumulation on the Fishing and Aquatic Life Support Beneficial Uses of California Water Bodies: A Review of Historic and Recent Data. Prepared for the State Water Resources Control Board, Sacramento, CA.

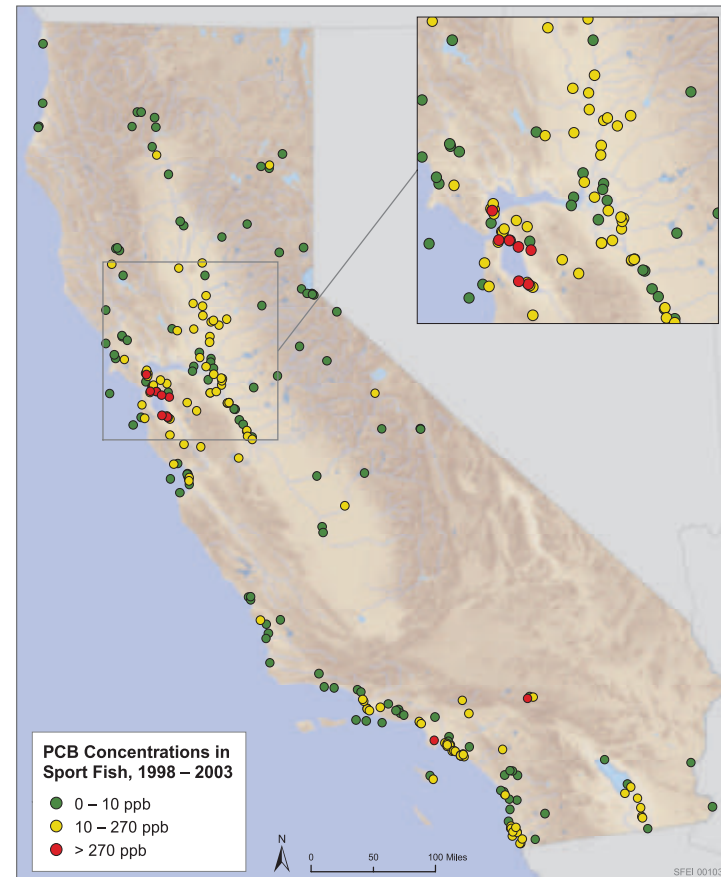
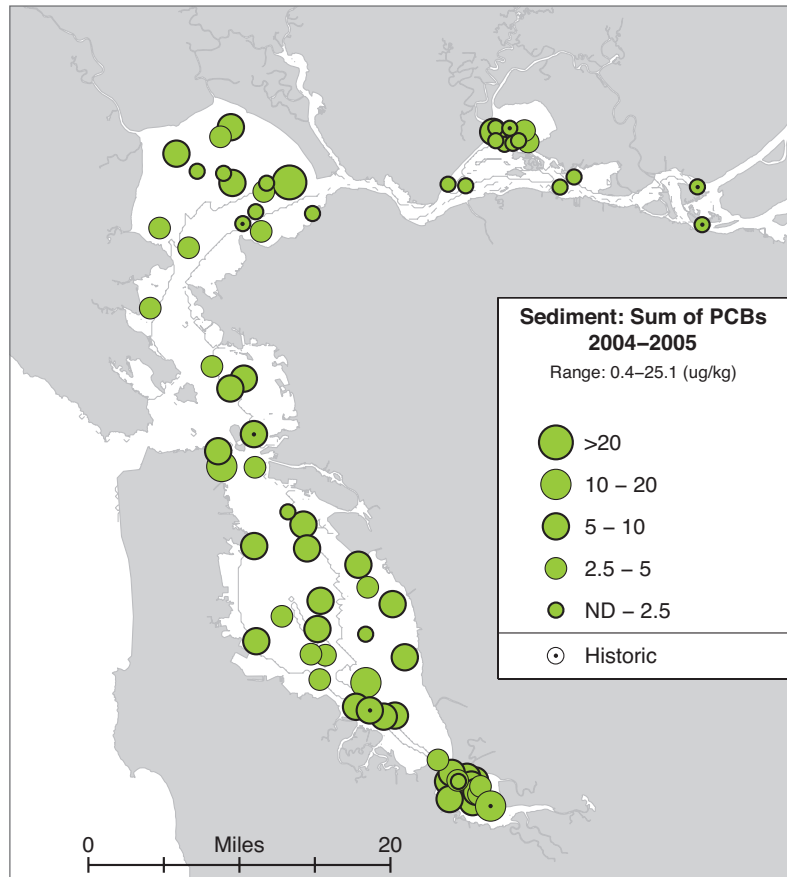
Contact: Letitia Grenier, San Francisco Estuary Institute, [letitia@sfei.org](mailto:letitia@sfei.org)

Mercury and gold mining have left a legacy of particularly severe mercury contamination in the Bay-Delta and its watershed. A Statewide review prepared by the San Francisco Estuary Institute in 2006 for the State Water Resources Control Board's Surface Water Ambient Monitoring Program found that 25 of 295 locations (9%) sampled from 1998 – 2003 had a sport fish species with a median mercury concentration above 0.9 ppm. Another 53% of the locations sampled from 1998 – 2003 had mercury concentrations in the range of 0.2 – 0.9 ppm, a range that exceeds the San Francisco Bay mercury TMDL target of 0.2 ppm for sport fish. Only 38% of the locations had concentrations below the 0.2 ppm target. The problem is worst (highest density of orange and red dots) in the San Francisco Bay-Delta and surrounding areas.



## → PCBs

PCB contamination remains one of the greatest water quality concerns in the Estuary, and PCB clean-up is a primary focus of the Water Board. PCBs are a problem because they accumulate to high concentrations in some Bay fish and pose health risks to consumers of those fish.



Footnote: Based on PCB measurements in edible tissue from a variety of fish species from 1998 - 2003. Dots represent sampling locations.

Reference: Davis, J.A., J.L. Grenier, A.R. Melwani, S. Bezalel, E. Letteney, E. Zhang. 2006. Draft Report: The Impact of Pollutant Bioaccumulation on the Fishing and Aquatic Life Support Beneficial Uses of California Water Bodies: A Review of Historic and Recent Data. Prepared for the State Water Resources Control Board, Sacramento, CA.

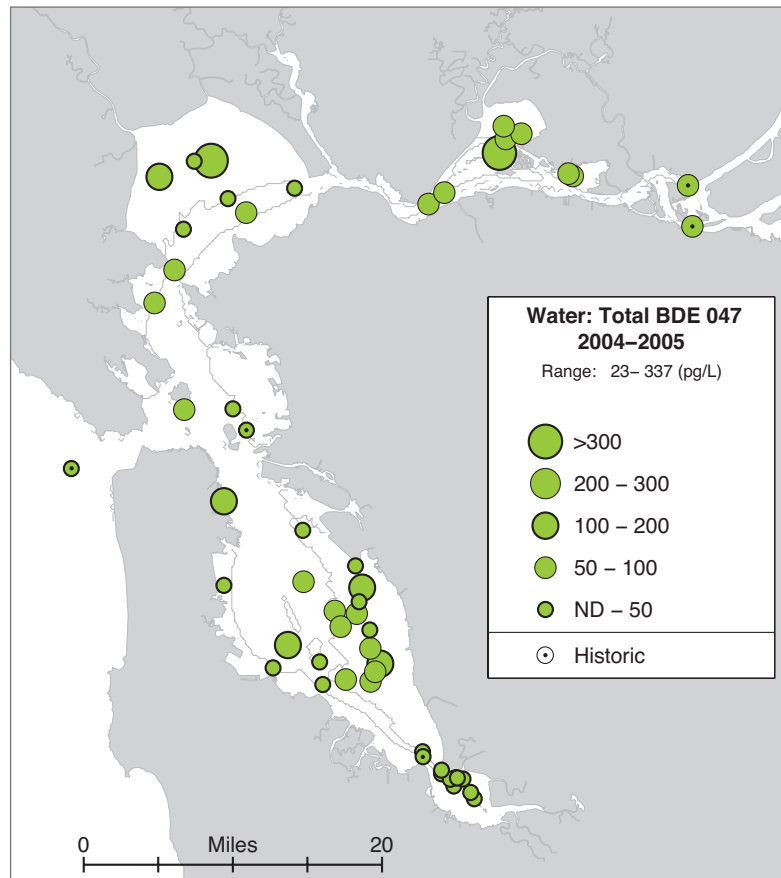
Contact: Jay Davis, San Francisco Estuary Institute, jay@sfei.org

■ ↑ In 2004 and 2005, 64 of 94 samples (68%) collected from the Bay exceeded 2.5 ppb. Concentrations were lower in Suisun Bay - 18 of the 30 samples below 2.5 ppb were from this segment. The highest concentration (25 ppb) was measured at a site in San Pablo Bay near Mare Island.

■ → Compared to other water bodies in California, PCB concentrations in San Francisco Bay are particularly high and appear to be unusually persistent. The Statewide review mentioned in the mercury section also included PCBs. Sport fish monitoring at 250 locations in California from 1998 - 2003 found that 4% of the locations had a species with a median concentration

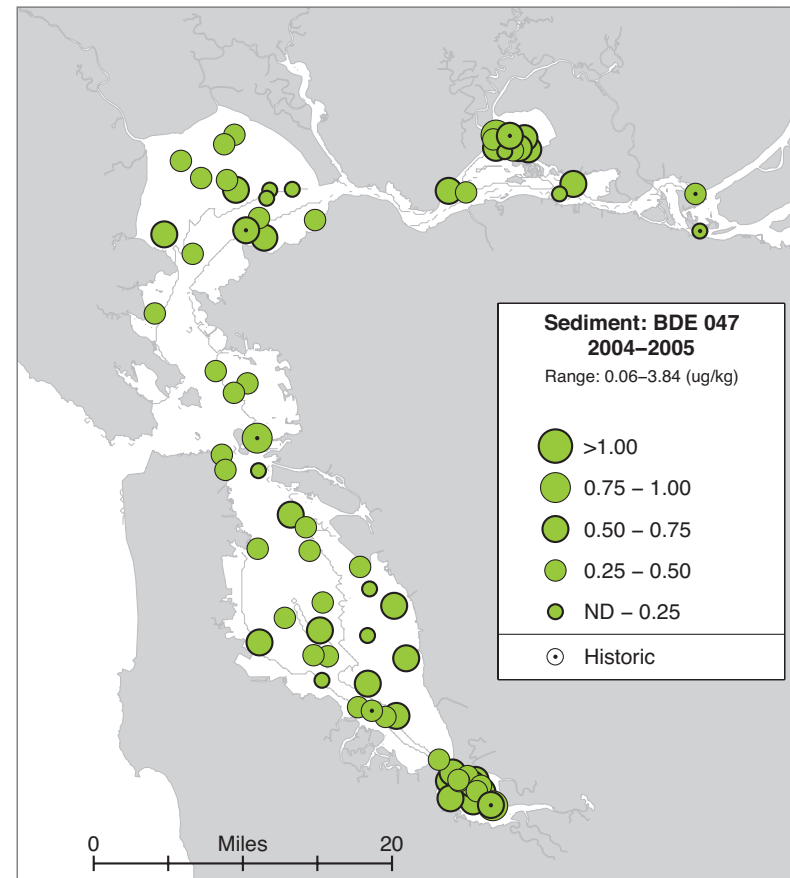
in a "very high" category (above 270 ppb). Forty-six percent of the locations sampled had concentrations between 10 and 270 ppb, a range that exceeds the proposed San Francisco Bay PCB TMDL target of 10 ppb for white croaker. Fifty percent of the locations sampled had concentrations below 10 ppb. Concentrations were highest in water bodies near major urban centers, including the Bay Area, Sacramento, Los Angeles, and San Diego. PCB concentrations in San Francisco Bay were particularly high, accounting for many of the locations in the "very high" category. In general, the review found that PCB concentrations are steadily declining across the State, with San Francisco Bay declining more slowly than many other areas.

PBDEs, a class of flame retardants that was practically unheard of in the early 1990s, have been increasing rapidly and are now known to be ubiquitous in the Estuary. The California Legislature has banned the use of two types of PBDE mixtures. Tracking the trends in these chemicals will be extremely important to determine what effect the ban will have and if further management actions are necessary. No regulatory guidelines exist yet for PBDEs.



Footnote: PBDE congener 47 shown as an index of total PBDEs. PBDE 47 is one of the most abundant congeners and was consistently quantified by the lab.

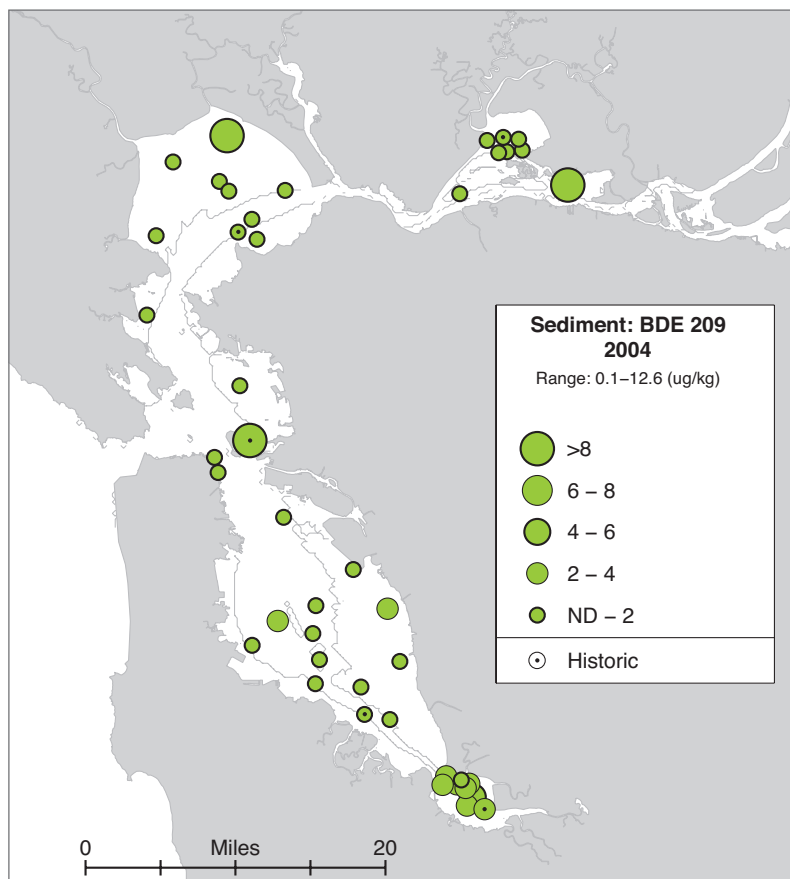
■ **Concentrations of PBDEs in water in 2004 and 2005 were relatively high in the northern Estuary.** The two highest PBDE concentrations in 2004 and 2005 were measured in Suisun Bay (337 pg/L) and San Pablo Bay (319 pg/L). Baywide, no samples fell in the 200 – 300 pg/L range, 5 in the 100 – 200 range, 24 in the 50 to 100 pg/L range, and 27 in the not detected to 50 pg/L range. Average concentrations were highest in Suisun Bay (112 pg/L) and lowest in the Lower South Bay (36 pg/L).



Footnote: PBDE congener 47 shown as an index of total PBDEs. PBDE 47 is one of the most abundant congeners and was consistently quantified by the lab.

■ **PBDEs in sediment in 2004 and 2005 were distributed relatively evenly throughout the Estuary.** The highest PBDE concentration in 2004 and 2005 by far was 3.8 ppb, measured at a station in the Lower South Bay. Only one other sample was above 1 ppb (from Suisun Bay at 1.0 ppb). Thirty percent of samples were in the 0.50 – 0.75 ppb range, and 44% were in the 0.25 – 0.50 ppb range. Average concentrations were highest in Lower South Bay (0.78 ppb), largely due to the influence of the one very high sample (3.8 ppb), and very consistent among the other segments (ranging from 0.38 to 0.43 ppb).

## → PBDEs continued

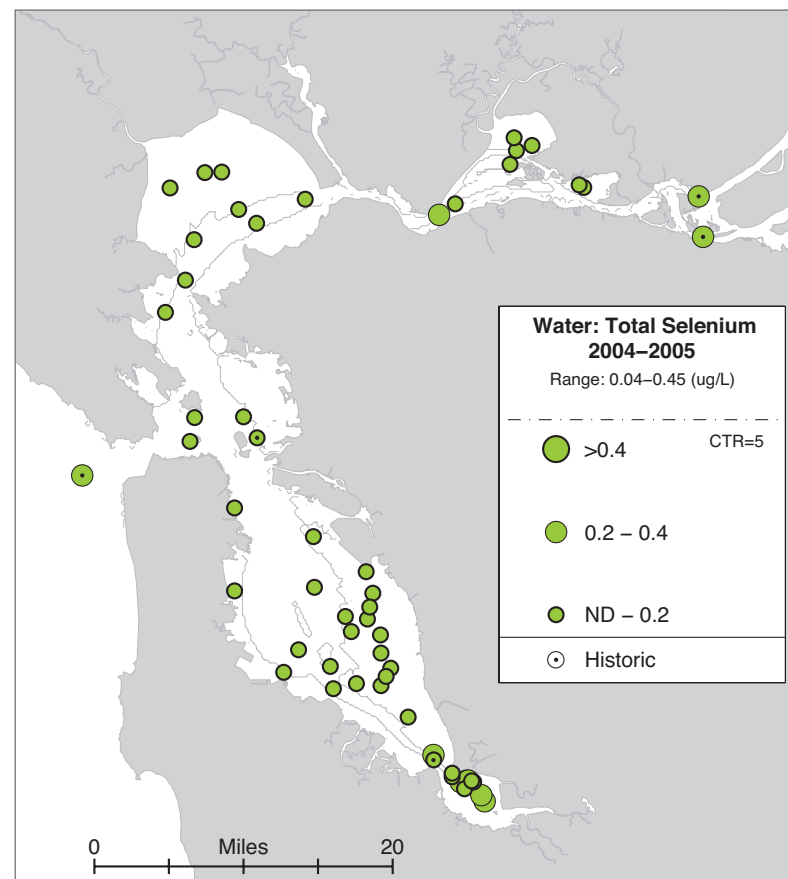


Footnote: 2005 data not available due to analytical problems.

■ **PBDE 209 is a congener that is abundant in the environment, but challenging to measure. PBDE 209 (also known as “decachlorobiphenyl”) is important because it represents the one remaining class of PBDE that can still be produced and sold in California.** In 2004 the RMP sediment organics lab (East Bay Municipal Utility District) successfully generated the first complete dataset on PBDE 209. Three samples in 2004 had concentrations above 8 ppb, with one each in Suisun, San Pablo, and Central Bays. Most samples (24 of 44, or 55%) had concentrations below 2 ppb. Average concentrations were highest in Lower South Bay (3.1 ppb), and ranged from 1.0 to 1.6 ppb in the other segments.

## → Selenium

Selenium contamination is a continuing concern in the Estuary. Selenium accumulates in diving ducks in the Bay to concentrations that pose a potential health risk to human consumers. Selenium concentrations also pose a threat to wildlife in the Estuary. Recent studies suggest that selenium concentrations may be high enough to cause deformities, growth impairment, and mortality in early life-stages of Sacramento splittail and white sturgeon.

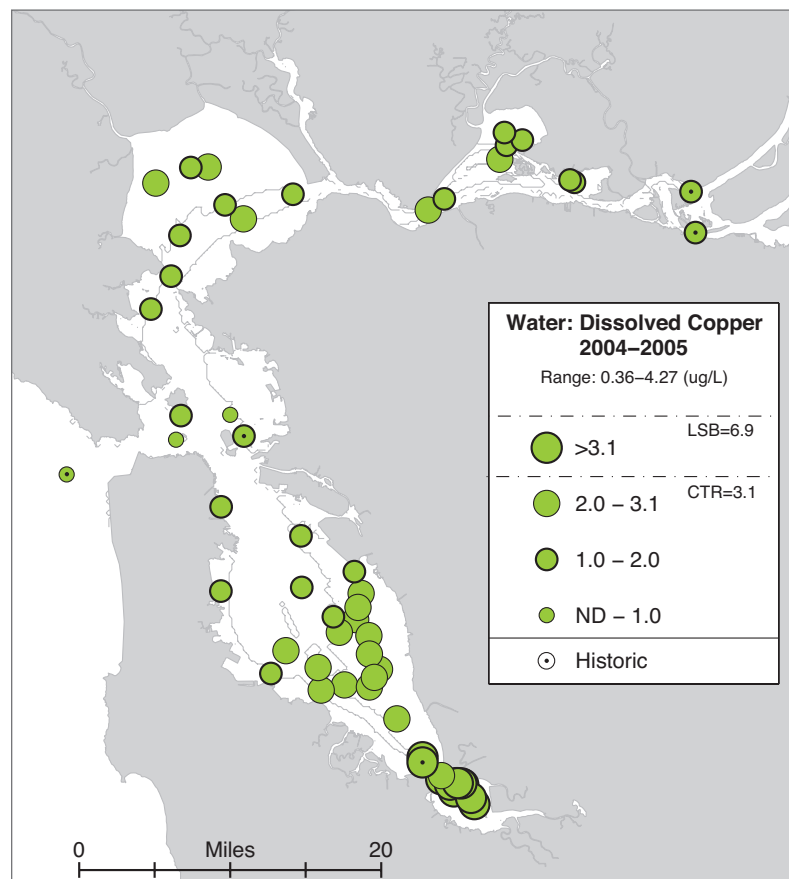


■ **Selenium concentrations in water are well below the water quality objective established by the California Toxics Rule (CTR), yet concerns still exist for human and wildlife exposure at current levels of contamination.** The highest concentration observed in water in 2004 and 2005 was 0.45 ug/L, less than one-tenth of the CTR objective. Most of the sites (52 of 62, 84%) had concentrations less than 0.2 ug/L. Lower South Bay had the highest average concentration (0.21 ug/L), and Suisun Bay the lowest (0.11 ug/L).



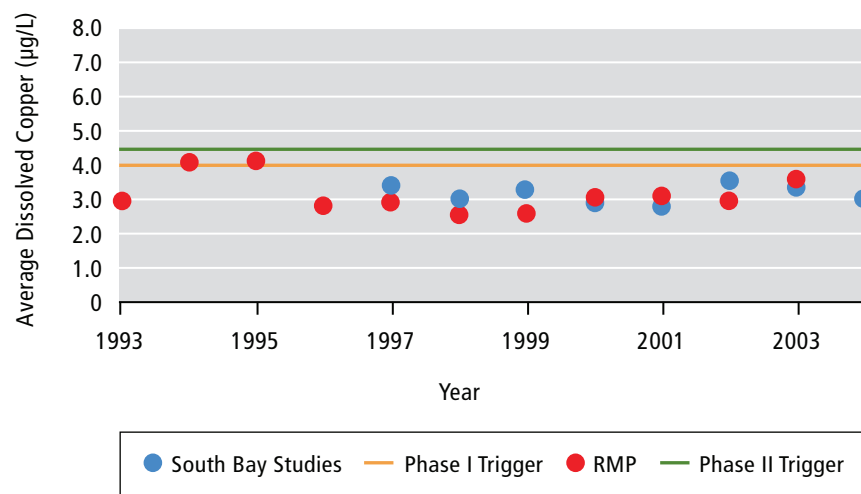
## → Copper

Copper was a major concern in the Estuary in the 1990s, as concentrations were frequently above the water quality objective. An evaluation of the issue by the Water Board and stakeholders led to new water quality objectives for copper and nickel in the Lower South Bay (less stringent but still considered fully protective of the aquatic environment), pollution prevention and monitoring activities, and the removal of copper from the 303(d) List.



■ In 2004 and 2005, only one water sample had a concentration above the copper objectives of 3.1 ug/L north of the Dumbarton Bridge or 6.9 ug/L south of the Dumbarton Bridge. The one sample was at the boundary of the South Bay and Lower South Bay segments, with a concentration of 3.2 ug/L. Concentrations in the Lower South Bay were high relative to the rest of the Bay (averaging 3.6 ug/L), but well below the site specific objective for that segment. The Water Board is in the process of adopting site-specific objectives for the Bay north of the Dumbarton Bridge.

Annual Average Dry Season Copper Concentrations

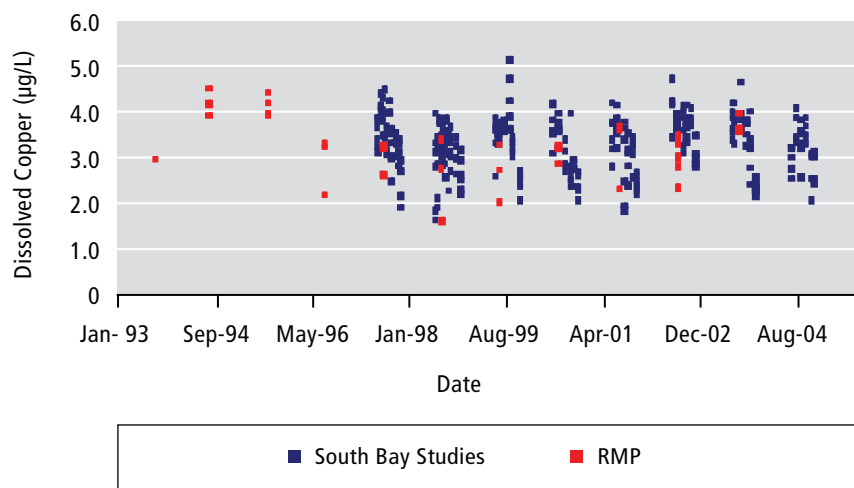


■ Copper concentrations in the Lower South Bay have been remarkably constant over the past nine years. In support of the effort to establish a site-specific objective (SSO) for dissolved copper in Lower South Bay and as part of its subsequent waste discharge permit, the City of San Jose conducted intensive monitoring of dissolved copper levels from 1997 to 2005. The City monitored copper concentrations monthly during the dry season at 10 stations. Results were compared to Lower South Bay Copper Action Plan trigger levels established by the Water Board in 2002 to implement the chronic copper SSO of 6.9 mg/L. The City also monitored

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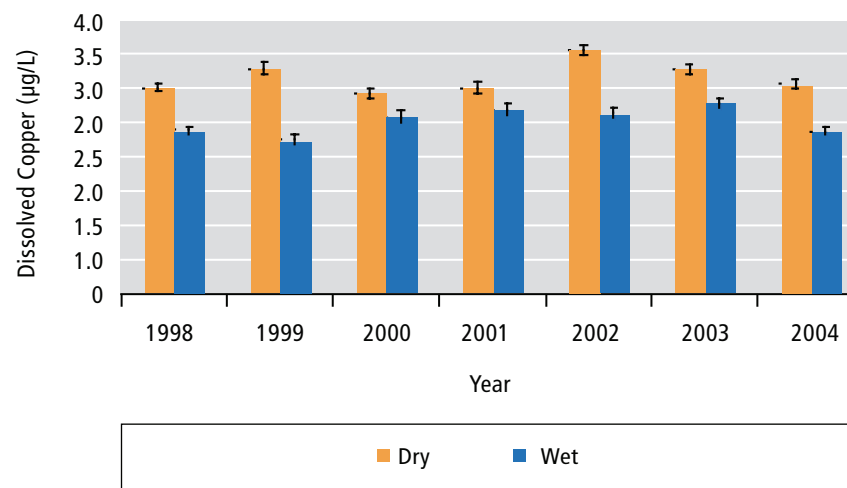
## → Copper continued

Lower South Bay Copper Concentrations



Footnote: Points represent individual samples.

Lower South Bay Annual Average Copper Concentrations



Reference: Dunlavy, E. and P. Schafer. 2006. Dissolved copper trends in lower South San Francisco Bay. Poster presented at the National Water Quality Monitoring Conference, San Jose, CA.

Contact: Eric Dunlavy, City of San Jose, [Eric.Dunlavy@sanjoseca.gov](mailto:Eric.Dunlavy@sanjoseca.gov)

dissolved copper concentrations at the same stations during the wet season. This additional monitoring, which was beyond the City's permit requirements, allows for characterization of seasonal and annual trends over a nine-year period for Lower South Bay and tributary stations.

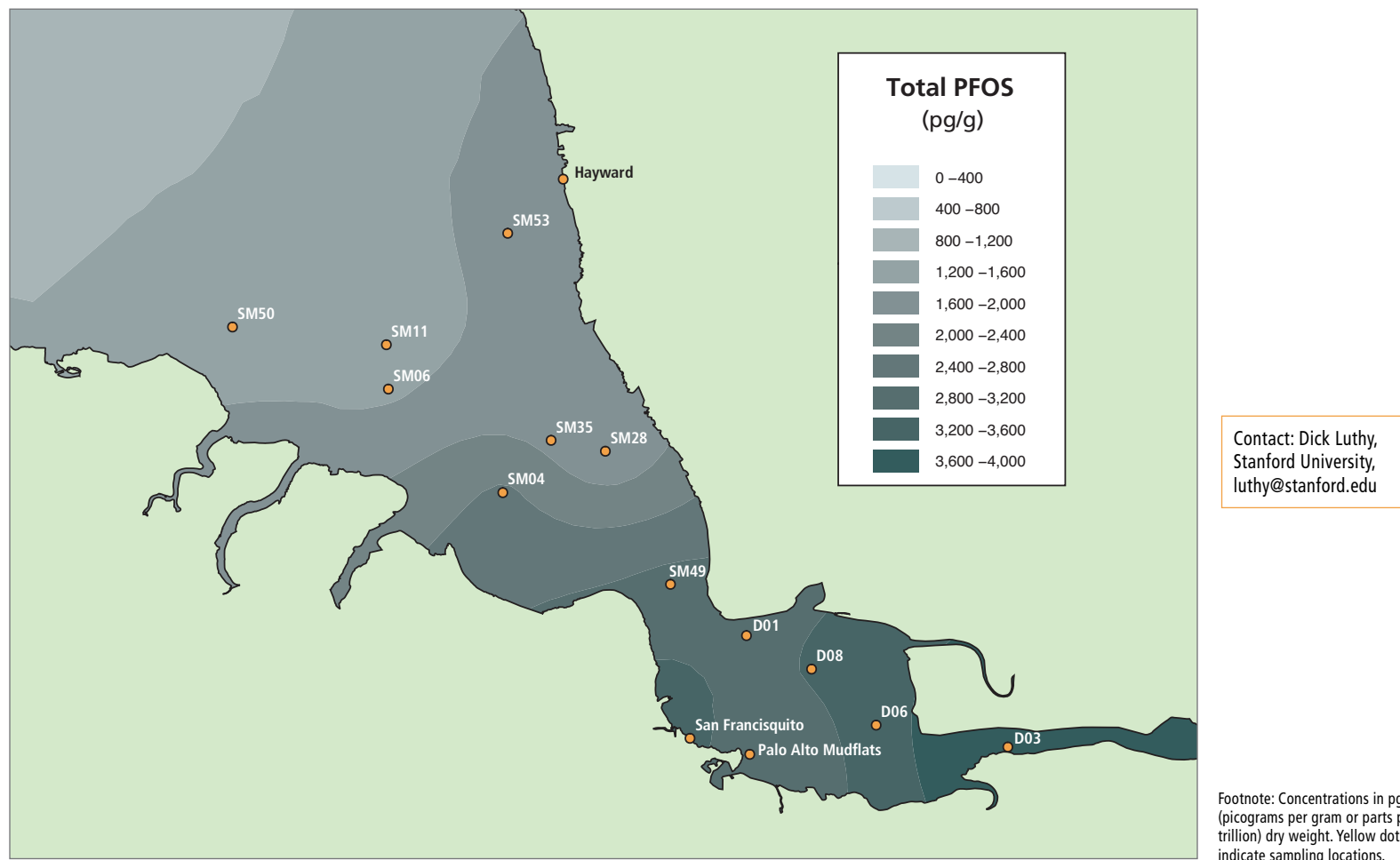
This monitoring has produced nine years of reliable data that allow for fine scale temporal and spatial comparisons of copper concentrations in the Lower South Bay. Average concentrations of dissolved copper have remained remarkably constant

with no change in overall average concentrations in nearly a decade. Data from the RMP and the City are in very good agreement. These data also demonstrate a consistent seasonal pattern in which concentrations are highest in the dry seasons (June-November), and lower during the intervening wet seasons. The City's intensive monitoring effort is a valuable tool for detecting very small changes in copper concentrations in Lower South Bay. However, due to the relatively static nature of dissolved copper, monitoring less frequently or relying on the RMP for future copper trigger monitoring may be viable alternatives.

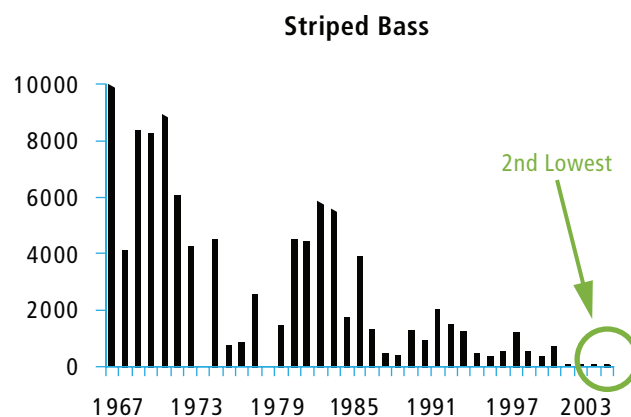
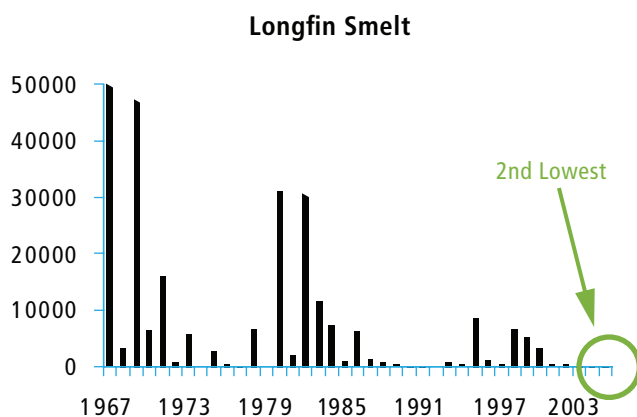
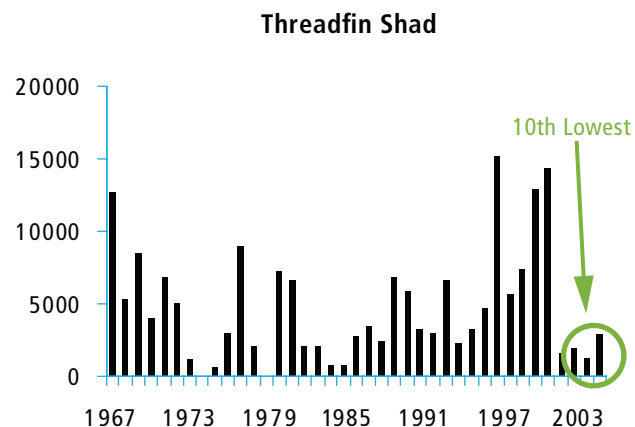
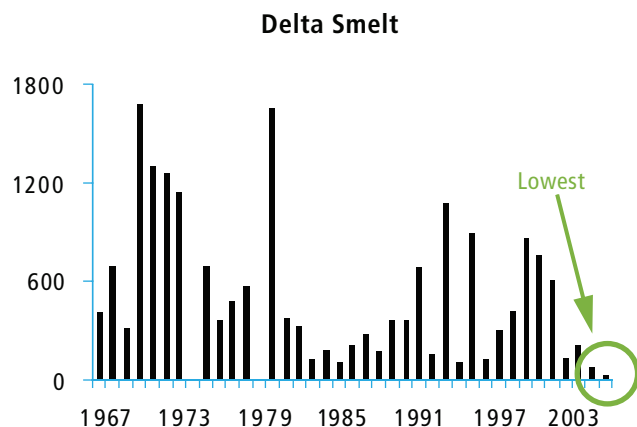


## Perfluorinated Chemicals

Perfluorinated chemicals (PFCs) are a class of synthetic compounds that have recently been discovered to be globally widespread in human blood and wildlife tissue at concentrations that are generating concern. PFCs have been manufactured for over 50 years and have been used extensively in a variety of commercial products including fire-fighting foams, stain repellants in textiles, and coatings for paper used in contact with food products (e.g., microwave popcorn bags). Common products that are either made with or contain PFCs include Teflon®, Gore-Tex®, and Scotchguard®. PFCs have been associated with a variety of toxic effects including cancer and developmental abnormalities.



■ In a pioneering study conducted in 2004, Chris Higgins and Dick Luthy of Stanford University measured PFCs in sediments from 14 locations in the South Bay. PFOS (perfluorooctane sulfonate) is one of the most abundant PFCs in environmental samples. PFOS was present in South Bay sediments with a gradient of increasing concentrations toward the very southern end of the Bay. Higgins and Luthy also measured PFOS and other PFCs in sludge from municipal wastewater treatment plants and found higher concentrations than those found in sediments. This spatial pattern, the sludge data, and information on the uses of PFCs in clothing and household products suggest that municipal wastewater is the likely source of these PFCs in the South Bay. The RMP is conducting a special study in 2007 to screen for these chemicals in the blood of harbor seals as an indicator of the degree of contamination of the Bay food web.

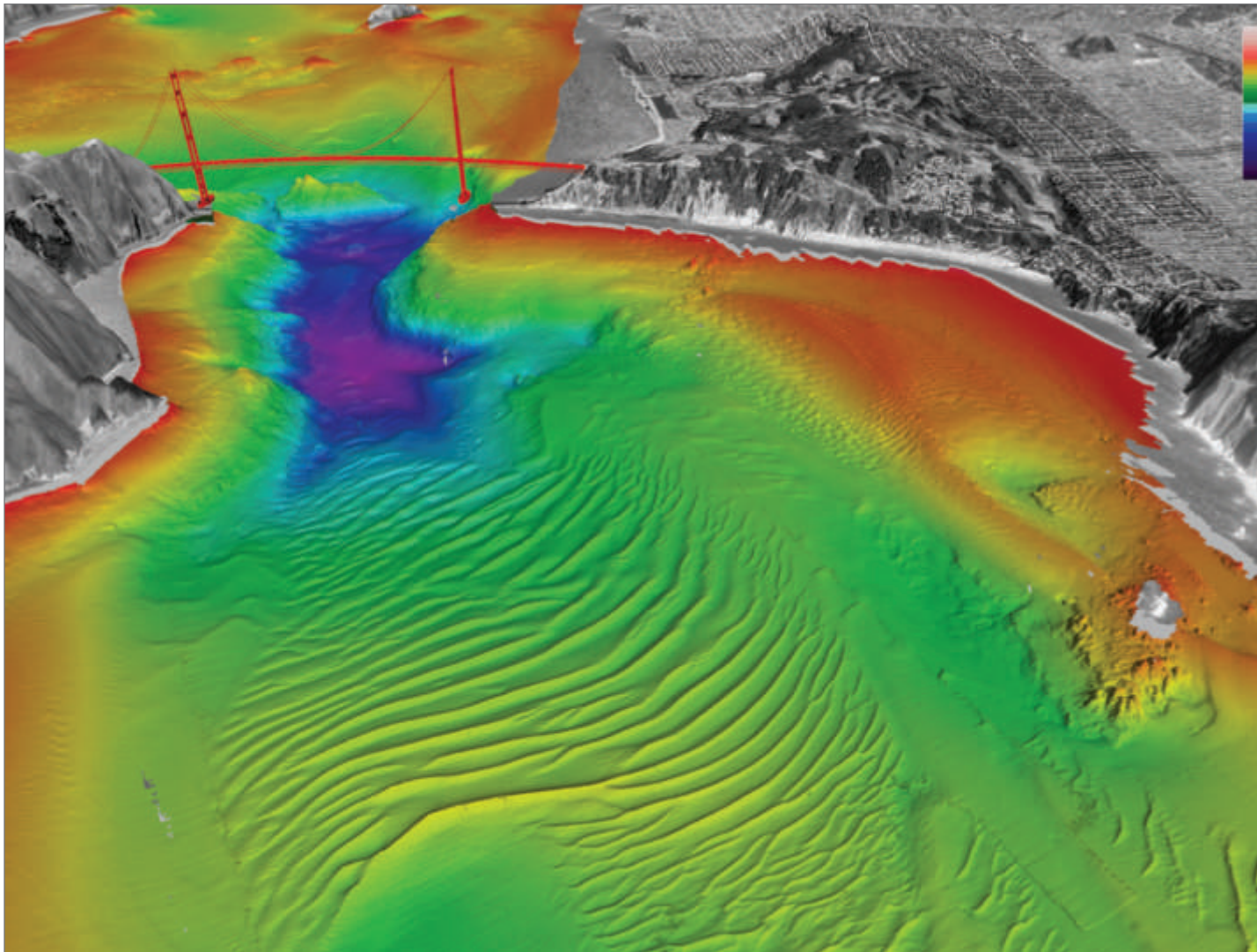


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Herbold.Bruce@epamail.epa.gov

Footnote: Data from the Fall Midwater Trawl.  
Circles indicate results for 2005. Additional  
information available at: [http://science.calwater.ca.gov/pod/pod\\_index.shtml](http://science.calwater.ca.gov/pod/pod_index.shtml)

■ **Several important fish species in the Estuary are showing serious declines.** Summer and fall abundance indices calculated by the Interagency Ecological Program (IEP) suggest recent marked declines in numerous pelagic fishes in the upper San Francisco Estuary (the Delta and Suisun Bay), known as the “pelagic organism decline.” Although several species show evidence of long-term declines, the recent low levels were unexpected given the relatively moderate winter-spring flows of the past several years. The fall indices have been collected for all but 2 of the last 30 years. The 2002-2005 fall indices include record or near-record lows for Delta smelt, striped bass, longfin smelt, and threadfin shad. In contrast, surveys of species in the more marine portions of San Francisco Bay did not show significant declines. Based on these findings, the problem appears to be limited to fish dependent on the upper Estuary.

The IEP is making a concerted effort to evaluate the potential causes of these declines. Some of the primary factors that are suspected to be acting individually or in concert to affect these species include toxic chemicals such as pyrethroid insecticides or toxins produced by newly abundant blue-green algae, invasive species that may be reducing the food supply for fish, and water project operations that may be removing a larger proportion of these populations in recent years.



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Footnote: A joint effort funded by the U.S. Geological Survey and the San Francisco District of the U.S. Army Corps of Engineers. This study was published in EOS, Transactions (July 18, 2006) and highlighted on the front page of the July 20, 2006 issue of the San Francisco Chronicle.

■ **The tides are the pulse of the Estuary, driving the movement of a huge volume of water into and out of the Estuary twice each day.** An incoming tide increases the volume of water in the Bay by about 25%. This tremendous quantity of water, about 500 billion gallons with each tide, must flow in and out of the relatively narrow constriction under the Golden Gate Bridge. Water flows through the Golden Gate are swift and powerful. In 2004 and 2005 Patrick Barnard, Dan Hanes, and David Rubin of USGS and colleagues at the California State University Monterey Bay Seafloor Mapping Lab, led by Rikk Kvitek, generated maps of the seafloor just outside the Golden Gate using multibeam sonar. The maps show waveforms created on the seafloor from the powerful tidal currents in the region. Massive sand waves are present at the mouth of the Bay (up to 220 m between peaks, 10 m high), dominated by coarse sand and gravel. These are some of the largest sand dunes in the world. The rapid currents passing through the Golden Gate scour the bottom to a depth of 113 m.



## Water Quality Trends at a Glance



**Thumbnail summaries of trends in some of the most important water quality indicators for the Bay**

Progress toward meeting guidelines

PCBs in sport fish

Mercury in sport fish

Selenium in diving ducks

PCBs in mussels

Total mercury in sediment

Percent toxic sediment samples

PAH concentrations in air

Annual rainfall in the Bay Area

Guadalupe River flow

Mercury loads from the Guadalupe River

Mercury loads from the Delta

Bay Area population

In-Bay disposal of dredged material

Restored wetland opened to tidal action

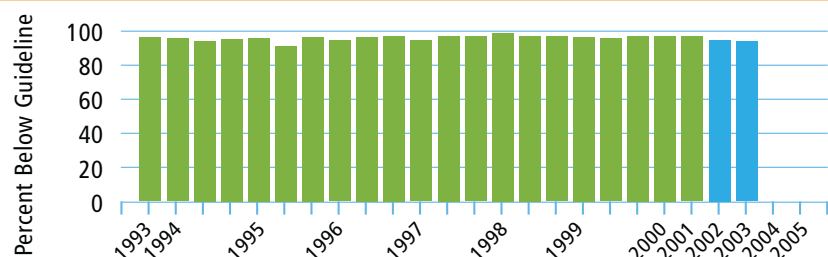




## Progress Toward Meeting Guidelines—Water



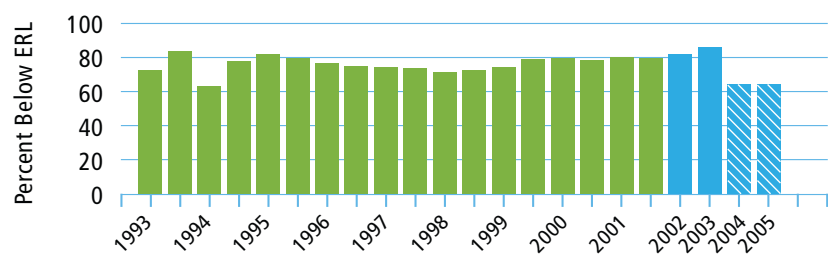
TREND



## Progress Toward Meeting Guidelines—Sediment



TREND



■ Historic Design

■ New Design

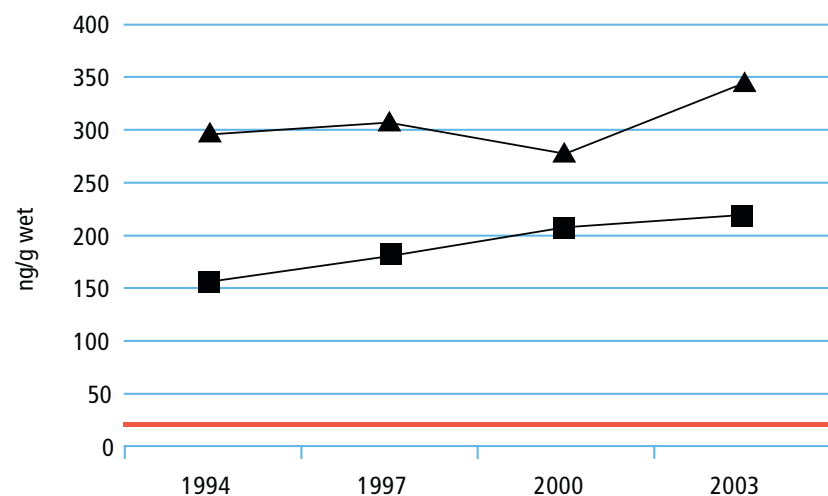
Footnote: Complete datasets for water in 2004 and 2005 not available at time of printing. These charts were created by calculating, for each sampling period and contaminant, the percentage of samples that met the guideline. Results for each contaminant were then averaged within each sampling period to obtain the values plotted on the chart. A value of 100% would mean all water or sediment samples met guidelines for all monitored contaminants. 2004 and 2005 sediment results (cross-hatching) are incomplete because not all contaminants were included at time of printing. Contact: John Oram, SFEI (joram@sfei.org).

**Progress Toward Meeting Contaminant Guidelines.** Most contaminant guidelines are being met. A relatively small number of problem contaminants make it rare to find water or sediment in the Estuary that meets all applicable guidelines. Achieving greater compliance with water and sediment guidelines poses a great challenge, largely because the Estuary is inherently slow to respond to reductions in inputs of persistent contaminants and because many problem contaminants have been distributed throughout the Estuary and its watershed.

## PCBs in Sport Fish



TREND



■ Shiner Surfperch

▲ White Croaker

Footnote: Baywide medians. Data from the RMP and Fairey et al. (1997).

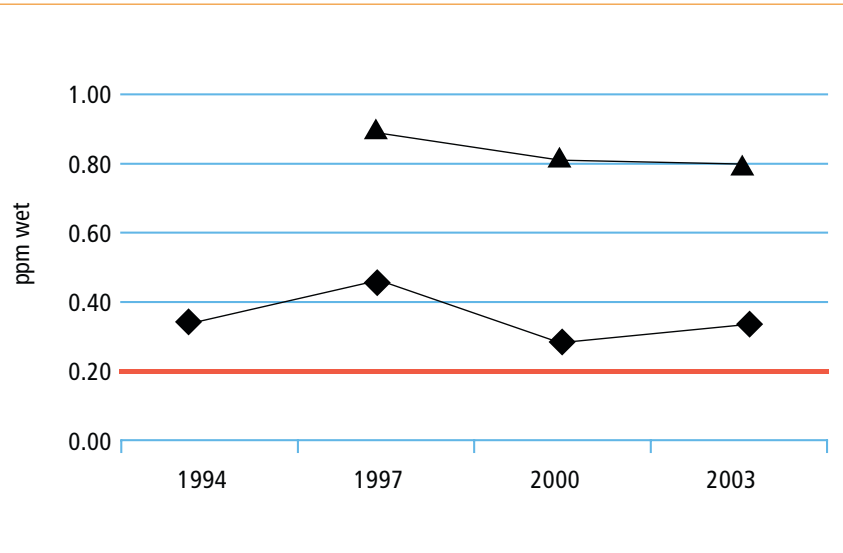
Contact: Jennifer Hunt, SFEI (jhunt@sfei.org).

**PCBs in Sport Fish.** Shiner surfperch and white croaker are sport fish species that accumulate high concentrations of PCBs and are consequently important indicators of PCB impairment. Concentrations have not changed significantly since monitoring began in 1994. Red line indicates the TMDL target for white croaker (10 ng/g).





## Mercury in Sport Fish



▲ Leopard Shark

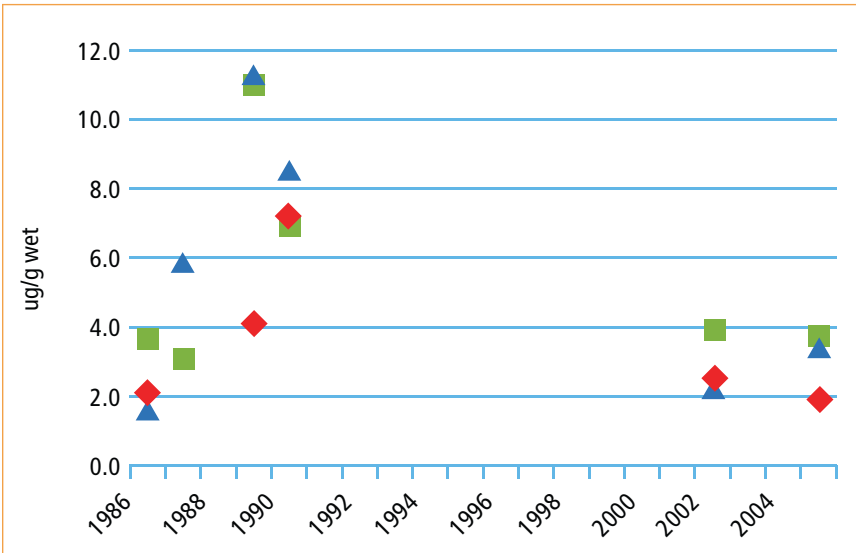
◆ Striped Bass

Footnote: Baywide medians. Leopard shark: 90-105 cm. Striped bass: 45-59 cm. Data from the RMP and Fairey *et al.* (1997).

Contact: Jennifer Hunt, SFEI (jhunt@sfei.org).

■ **Mercury in Sport Fish.** Leopard shark and striped bass are the two species that accumulate the highest concentrations of mercury and are therefore important indicators of mercury impairment. Mercury concentrations have shown some variation, but no clear long-term trend. Red line indicates TMDL target for sport fish tissue (0.2 ppm).

## Selenium in Diving Ducks



■ Suisun

▲ San Pablo

◆ South

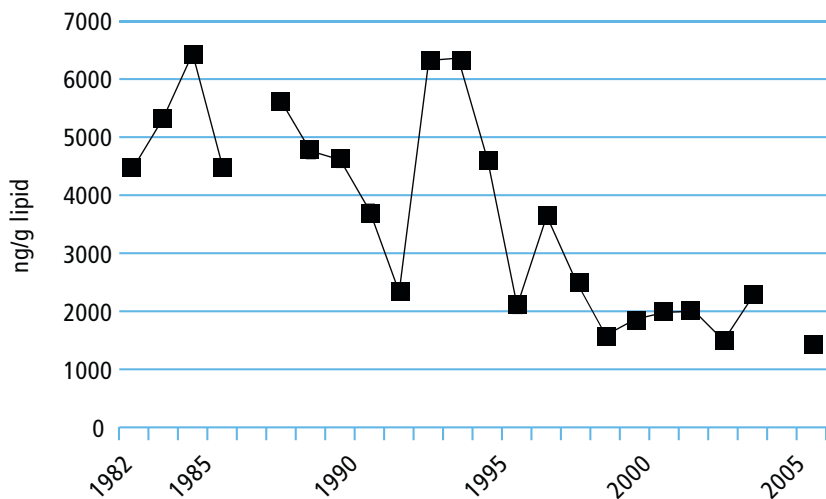
Footnote: Concentrations in breast muscle. Each recent point represents a mean of 10 birds. Earlier data from the Selenium Verification Study (White *et al.* 1989).

Contact: Jennifer Hunt, SFEI (jhunt@sfei.org).

■ **Selenium in Diving Ducks.** Consumption advisories for surf scoter and scaup have been in effect since 1986 and 1988, respectively, a primary reason for the inclusion of selenium on the 303(d) list of impaired waterbodies. Concentrations measured by the RMP in 2002 and 2005 were low relative to earlier measurements, but variability from year to year has been high.



## PCBs in Bivalves

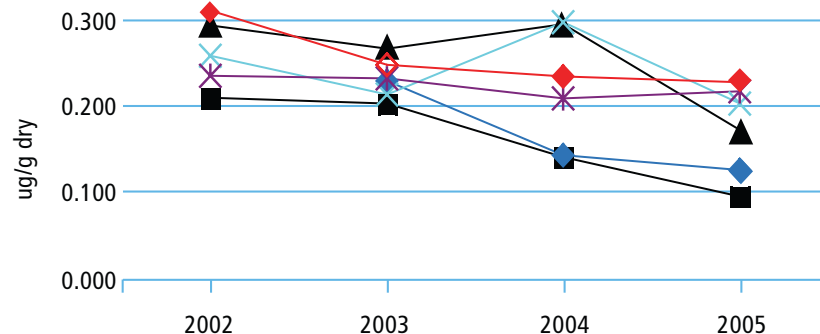


Footnote: Points represent single analyses of composite samples collected in summer. Data from the State Mussel Watch Program (1980-1992) and RMP (1993-present). The 2004 data point is missing due to analytical problems.

Contact: Jennifer Hunt, SFEI ([jhunt@sfei.org](mailto:jhunt@sfei.org)).

■ **PCBs in Mussels.** Monitoring of mussels in the Bay provides the best available long-term record of trends in PCBs and other organic contaminants in the Estuary. Data shown are for one location (Yerba Buena Island), which has the best time series. Concentrations have declined slowly since 1982.

## Total Mercury in Sediment



■ Suisun Bay      ▲ San Pablo Bay      ◆ Rivers  
× Central Bay      \* South Bay      ◆ Lower South Bay

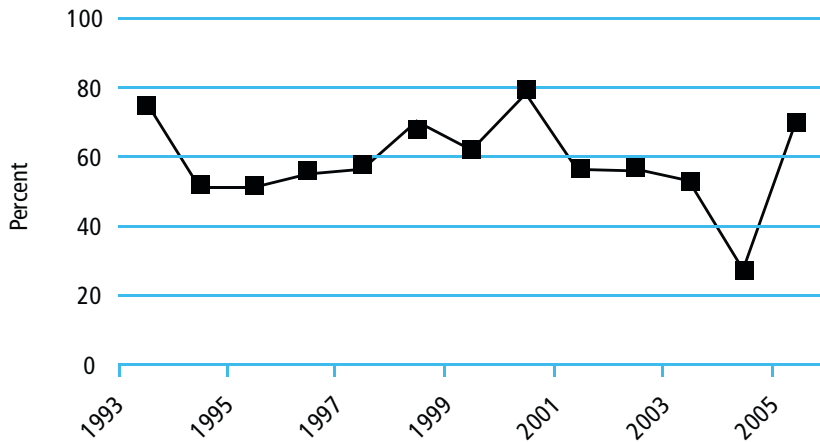
Footnote: Concentrations for the Rivers were not detectable in 2002.

Contact: Sarah Lowe, SFEI ([sarahl@sfei.org](mailto:sarahl@sfei.org)).

■ **Annual Average Total Mercury in Sediment by Bay Segment.** In 2002, the RMP began sampling in a manner that yields representative average concentrations for each Bay segment. The lowest concentrations for five of six segments were observed in 2005. Additional sampling in years to come will establish whether these data are indicative of a real decline, or are merely pronounced interannual fluctuations.



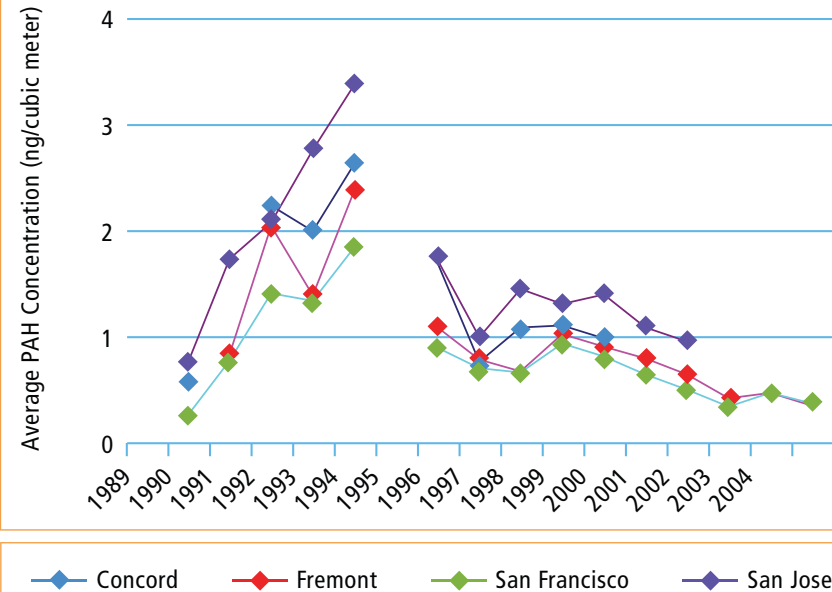
## Percent Toxic Sediment Samples



Footnote: Sediment samples are tested using amphipods and mussel larvae.  
Contact: Sarah Lowe, SFEI ([sarahl@sfei.org](mailto:sarahl@sfei.org)).

■ **Percent of RMP Sediment Samples Causing Toxicity in Lab Tests.** The frequent occurrence of toxic sediment samples in the Estuary is a major concern. In every year since sampling began in 1993, 26% or more of sediment samples have been determined to be toxic to one or more test species.

## PAH Concentrations in Air



Footnote: Sum of concentrations of benzo[b]fluoranthene, benzo[a]pyrene, benzo[g,h,i]perylene, benzo[k]fluoranthene, dibenz[a,h]anthracene, and indeno[1,2,3-cd]pyrene collected from 1989-2004. These PAHs were associated with particulate matter and not in the gaseous phase. Data from California Air Resources Board, [www.arb.ca.gov/adam/toxics/sitesubstance.html](http://www.arb.ca.gov/adam/toxics/sitesubstance.html)  
Contact: Jennifer Hunt, SFEI ([jhunt@sfei.org](mailto:jhunt@sfei.org)).

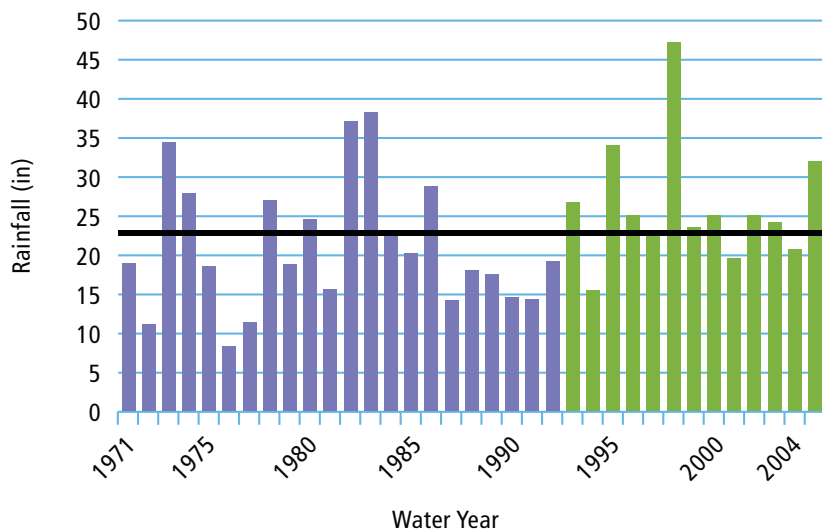
■ **Annual Average PAH Concentrations in Air.** Atmospheric deposition is a primary source of PAHs to the Estuary, both through direct deposition to the Bay surface and indirectly through deposition in the watershed followed by transport in stormwater. Concentrations have been declining since the mid-1990s.



## Annual Rainfall in the Bay Area



TREND



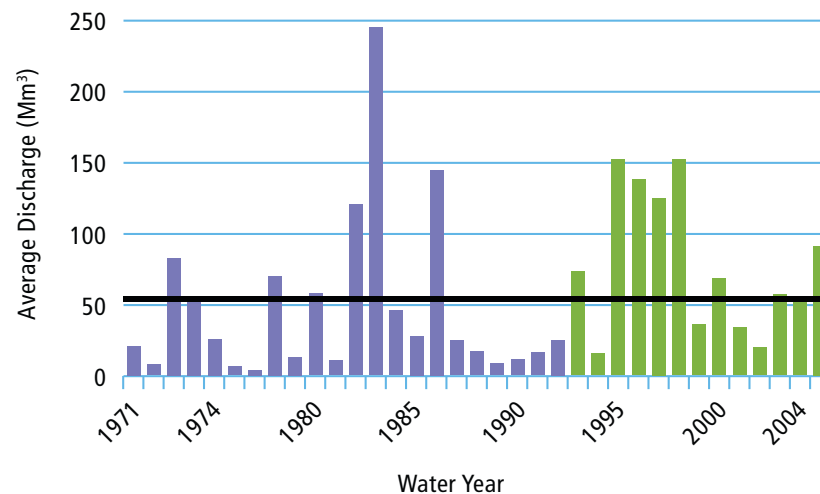
— Long-term Average = 22 inches (1850-Present)

Footnote: Annual rainfall measured in San Francisco. Green bars coincide with RMP monitoring. Source: Golden Gate Weather Services and Western Regional Climate Center.

## Guadalupe River Flow



TREND



— Long-term Average = 55 Mm³

Footnote: Green bars correspond to years of RMP monitoring. Average flow is for the period 1971 – 2000.

Source: U.S. Geological Survey.

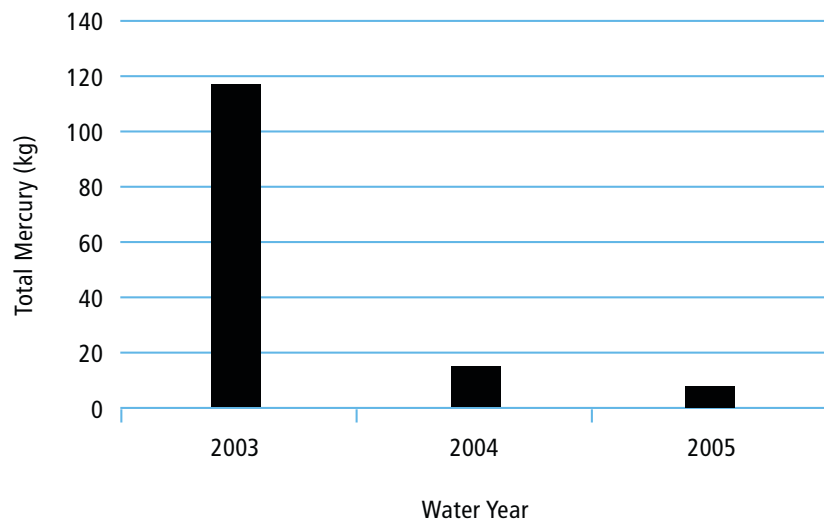
Contact: Lester McKee, SFEI  
(lester@sfei.org).

■ **Annual Rainfall in the Bay Area** is an index of freshwater flow into the Bay, which has a large influence on pollutant transport into the Bay and general water quality in the Bay. Freshwater flow fluctuates widely from year-to-year, making it more difficult to measure trends in pollutant inputs and water quality. Records date back to 1850.

■ **Annual Average Flow from the Guadalupe River.** Stormwater flows are a primary influence on loads from local Bay Area watersheds. Flows from the Guadalupe River, a major contributor of mercury to the Bay, were relatively high in the early years of the RMP (1995 through 1998), and at or below the long-term average from 1999 through 2004. A similar pattern was observed for Alameda Creek and Napa River.



## Mercury Loads from the Guadalupe River



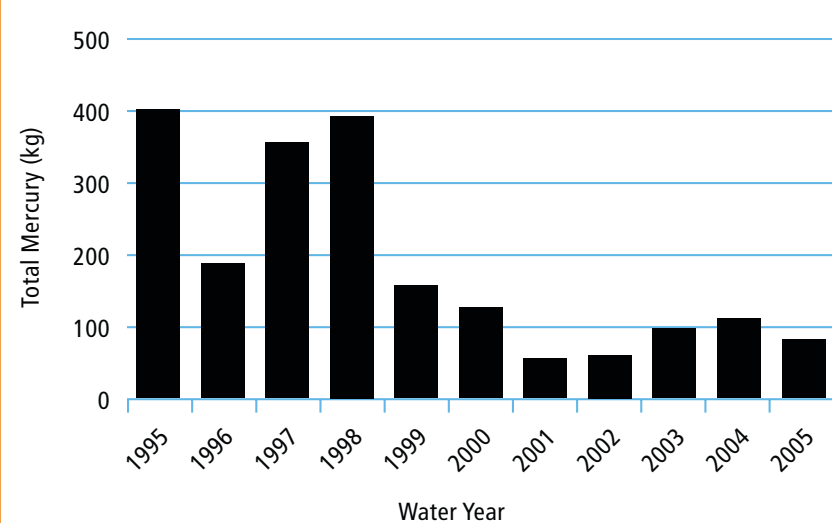
Estimated Long-term Average = 140 kg

Footnote: Total loads for each water year (Oct 1 – Sep 30). Additional matching funding for this RMP study was provided by the CEP, USACE/SCVWD, and SCVURPPP.

Contact: Lester McKee, SFEI (lester@sfei.org).

■ **Annual Loads of Mercury from the Guadalupe River.** The Guadalupe River is a significant pathway for transport of mercury and other pollutants into the Bay, and the first small tributary to the Bay selected for a rigorous evaluation of loads. Loads fluctuate from year to year due to variation in rainfall intensity, water flow, and other factors.

## Mercury Loads from the Delta



Average (1995-2005) = 182 kg

Footnote: Total loads for each water year (Oct 1 – Sep 30). Loads from 2002 – 2005 are based on field data. Loads for earlier years are estimated from relationships observed between suspended sediment and mercury in 2002 -2005.

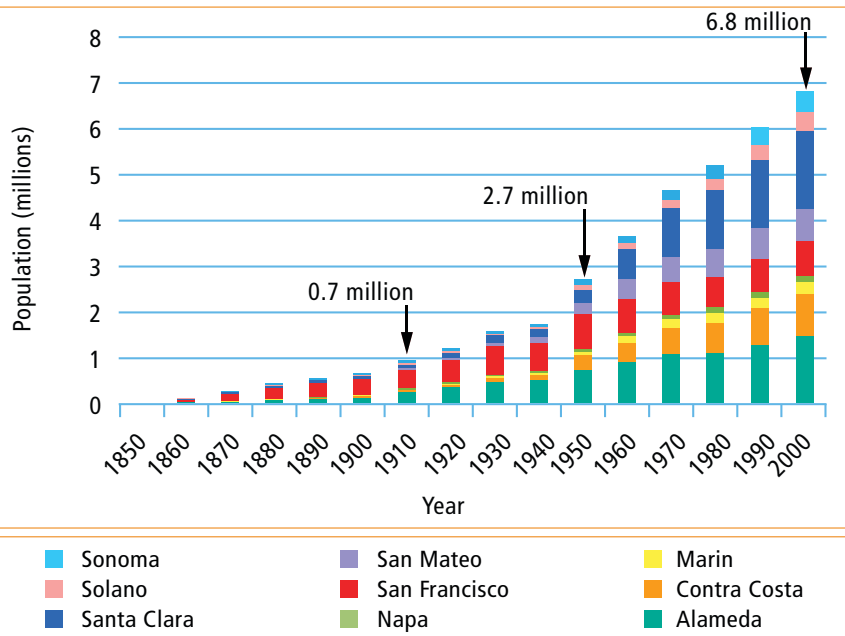
Contact: Lester McKee, SFEI (lester@sfei.org).

■ **Annual Loads of Mercury from the Delta.** Delta outflow carries significant loads of mercury and other pollutants from the Central Valley watershed into the Bay. A RMP study has estimated loads from 1995 to present. Recent sampling conducted during the high flows of January 2006 will help to refine these estimates.



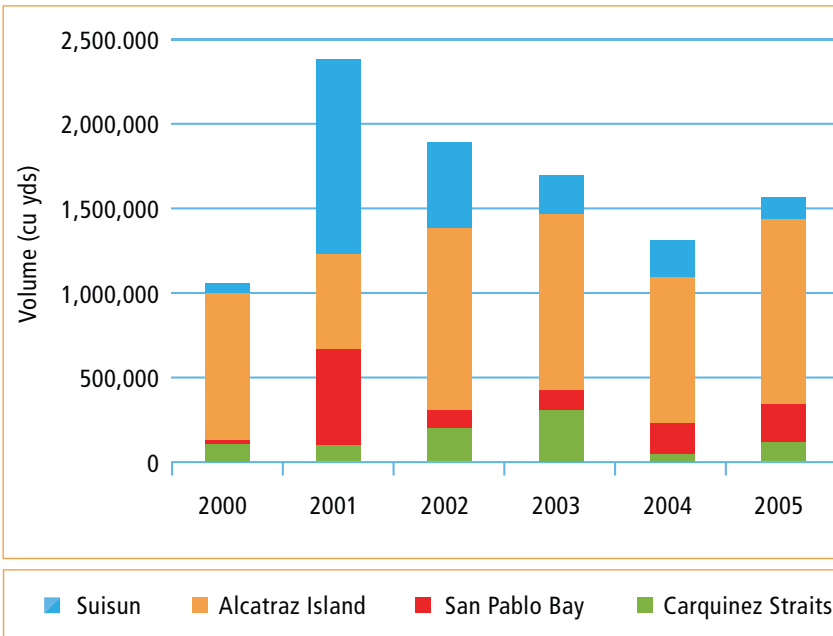


## Bay Area Population



Footnote: Data from the Association of Bay Area Governments.  
Contact: Lester McKee, SFEI (lester@sfei.org).

## In-Bay Disposal of Dredged Material



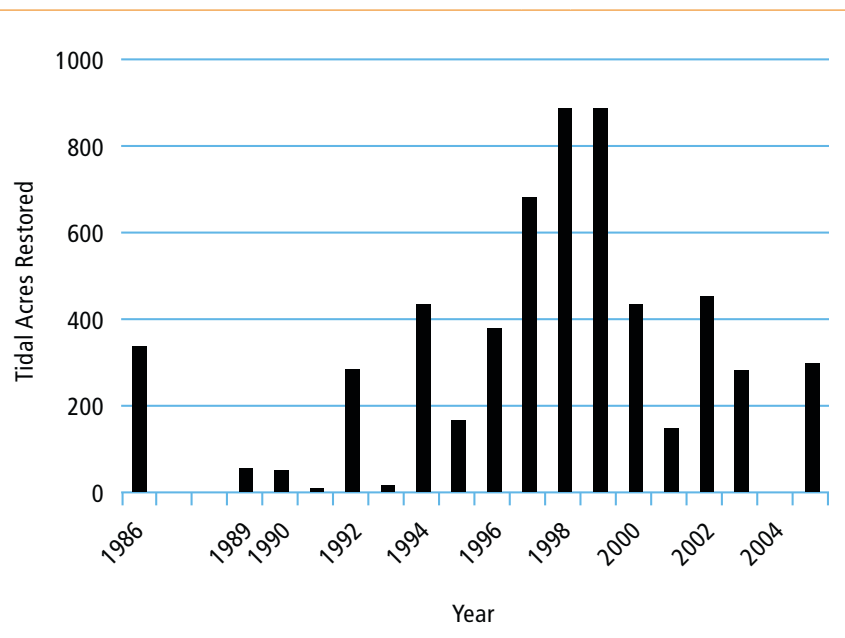
Footnote: Data from the U.S. Army Corps of Engineers.  
Contact: Meg Sedlak, SFEI (meg@sfei.org).

**Bay Area Population.** The large and growing human population of the Bay Area places continuing pressure on Bay water quality through increases in wastewater volume, urbanization, vehicle usage, and other mechanisms. The population of the Bay Area reached 6.8 million in 2000, and is predicted to increase by another million by 2020.

**Annual Volume of Dredged Material Disposed of in the Bay.** Dredged material disposal is one of the pathways for pollutant redistribution within the Bay. In 2005, 1.56 million cubic yards of dredged material were disposed of at the four disposal sites in the Bay. Other dredged material was disposed of in the ocean and used in restoration projects in upland areas. Dredged material management agencies plan to reduce in-Bay disposal to 1 million cubic yards per year in the next 10 years.



## Restored Wetland Opened to Tidal Action



Footnote: Data from the Bay Area Wetland Tracker ([www.wetlandtracker.org](http://www.wetlandtracker.org)).

Contact: Josh Collins, SFEI ([josh@sfei.org](mailto:josh@sfei.org)).

■ **Acres of Salt Pond or Other Habitat Opened to Tidal Action.** San Francisco Bay is home to the most ambitious tidal wetland restoration project ever on the west coast of North America, the South Bay Salt Pond Restoration Project, which plans to restore 16,500 acres of San Francisco Bay salt ponds to tidal marsh, and several other major tidal wetland restoration projects. These projects could have a significant influence on Bay water quality, with the potential for increased mercury in the food web a particular concern. The number of acres restored is expected to increase in the near future.



California Clapper Rail. Photo courtesy of John Ross, SFEI.



SAN PABLO BAY

PACIFIC OCEAN

The big picture of water quality in the Estuary

SOUTH BAY

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# PCBs in San Francisco Bay

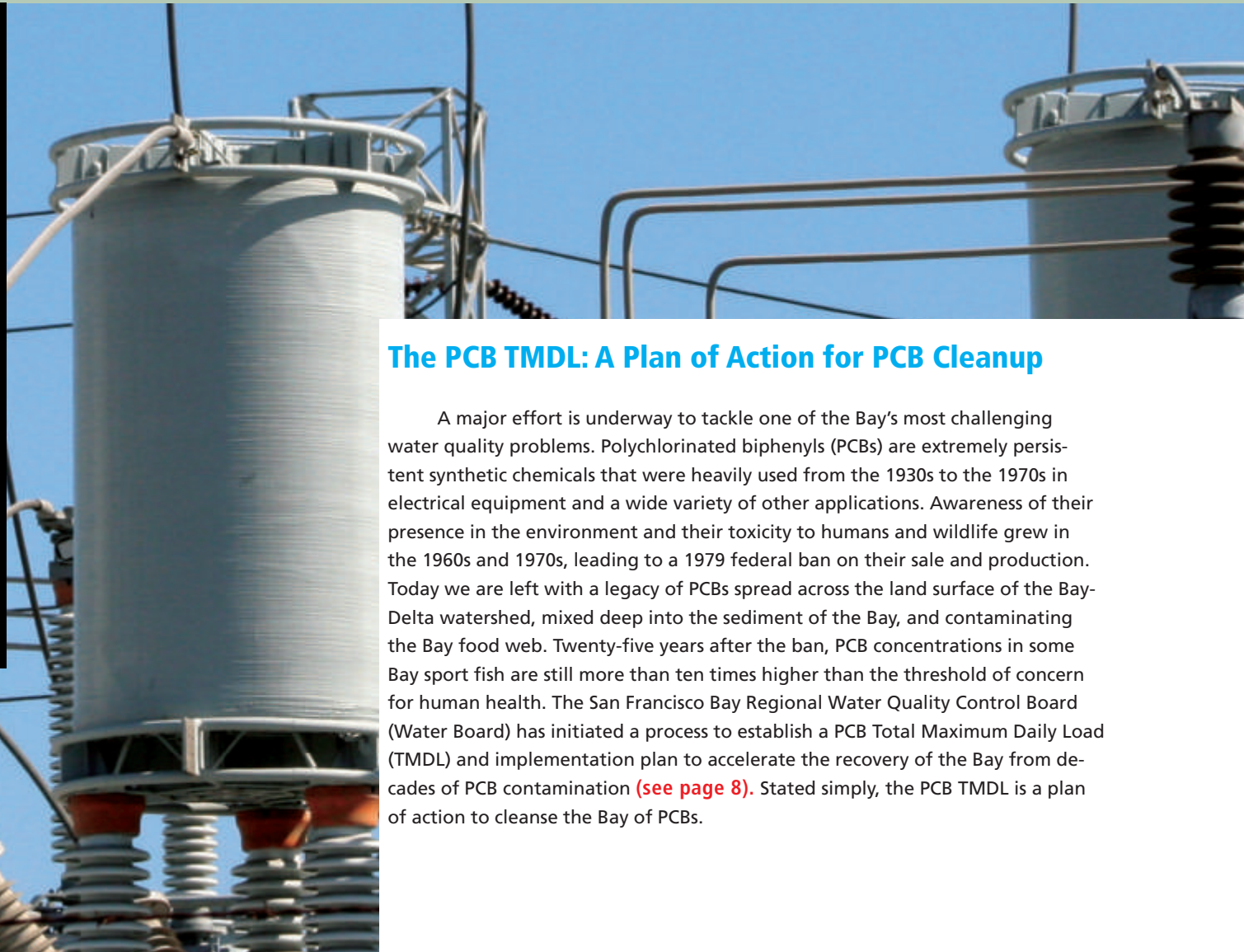
Jay A. Davis<sup>1</sup> (jay@sfei.org), Fred Hetzel<sup>2</sup>, and John J. Oram<sup>1</sup>

<sup>1</sup> San Francisco Estuary Institute, Oakland, CA. <sup>2</sup> San Francisco Bay Regional Water Quality Control Board



## Key Points

- The Water Board is developing a plan, the PCB TMDL, to tackle one of the Bay's most challenging water quality problems
- PCBs are extremely persistent chemicals that were used in a variety of applications, leading to their widespread distribution across the landscape
- PCBs in the Bay are considered a problem because they pose health risks to both humans and wildlife
- Recovery from the current level of PCB contamination appears likely to take several decades
- Opportunities for significant reduction of PCB inputs to the Bay are greatest for urban runoff and contaminated sites where deposits of PCBs are concentrated and most amenable to cleanup



## The PCB TMDL: A Plan of Action for PCB Cleanup

A major effort is underway to tackle one of the Bay's most challenging water quality problems. Polychlorinated biphenyls (PCBs) are extremely persistent synthetic chemicals that were heavily used from the 1930s to the 1970s in electrical equipment and a wide variety of other applications. Awareness of their presence in the environment and their toxicity to humans and wildlife grew in the 1960s and 1970s, leading to a 1979 federal ban on their sale and production. Today we are left with a legacy of PCBs spread across the land surface of the Bay-Delta watershed, mixed deep into the sediment of the Bay, and contaminating the Bay food web. Twenty-five years after the ban, PCB concentrations in some Bay sport fish are still more than ten times higher than the threshold of concern for human health. The San Francisco Bay Regional Water Quality Control Board (Water Board) has initiated a process to establish a PCB Total Maximum Daily Load (TMDL) and implementation plan to accelerate the recovery of the Bay from decades of PCB contamination (see page 8). Stated simply, the PCB TMDL is a plan of action to cleanse the Bay of PCBs.



Development of the PCB TMDL by the Water Board began shortly after the 1998 303(d) listing, with reports being issued on sources and loadings, impairment, and a TMDL Project Report (SFBRWQCB 2004). Development of the TMDL has included extensive stakeholder involvement, information gathering, and the improvement of analytical tools to predict the response of the Bay to load reductions. In the PCB TMDL process the emphasis is shifting away from enforcement of water quality objectives and toward enforcement of targets that are more directly linked with impairment, particularly PCB concentrations in sport fish and wildlife prey. Through the TMDL process, attention is being more sharply focused on the PCB sources that appear controllable and are contributing most to PCB impairment in the Bay.

## A PCB Profile

PCBs are a family of chemicals that were widely used for many decades, are extremely stable in the environment, have a strong tendency to accumulate in living organisms, and continue to pose health risks to humans and wildlife. The term “polychlorinated biphenyl” refers to a family of 209 individual chemicals (called “congeners”) based on combination of a two-ringed carbon skeleton with varying numbers of chlorine atoms (Figure 1). In the U.S., PCBs were sold as mixtures of many congeners known as “Aroclors.”

Due to their resistance to electrical, thermal, and chemical processes, PCBs have been used in a wide variety of applications from the time of their initial commercial production in 1929. PCBs were most commonly used as insulators in electrical equipment such as transformers and capacitors. Electrical utilities and industries consuming large quantities of electricity used the greatest quantities of PCBs. PCBs were also used in many other applications, including hydraulic fluids, lubricants, inks, and as a plasticizer. One example of a common use of PCBs was in one billion electrical ballasts installed in fluorescent light fixtures throughout the U.S.. U.S. sales of PCBs peaked in 1970 at 73 million pounds (Figure 2). Trends in PCB release to the environment, including San Francisco Bay, approximately matched trends in PCB sales.

Figure 1

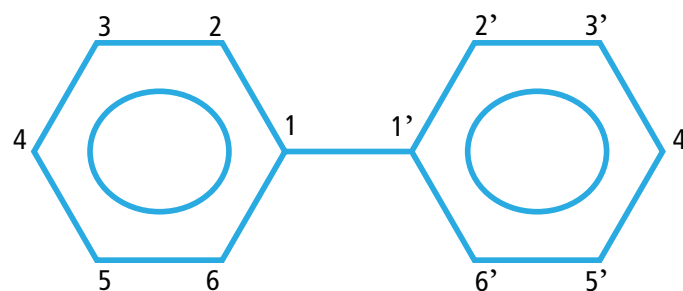
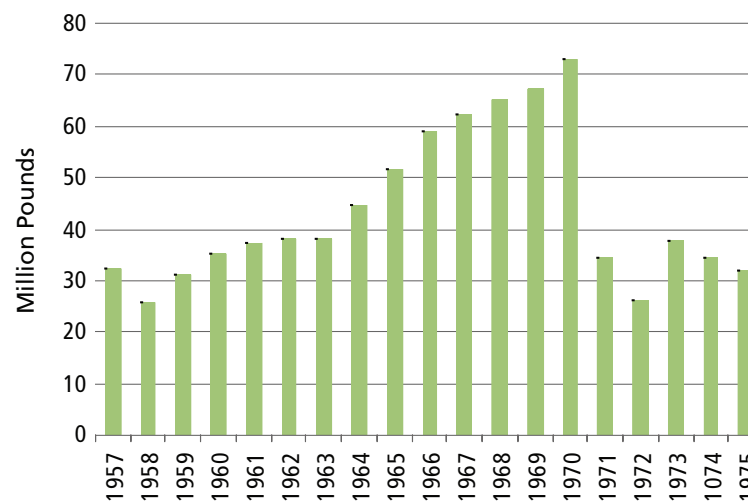
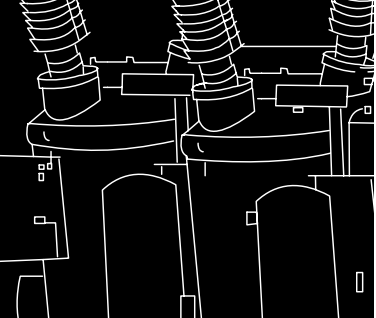


Figure 2



**Figure 1. Structure of the PCB molecule.** Chlorine atoms can be attached at any of the positions numbered 2 through 6. A total of 209 different variations (known as “congeners”) are possible.

**Figure 2. PCB sales in the U.S., 1957 – 1975.** Trends in PCB releases to the environment, including San Francisco Bay, approximately matched trends in PCB sales.



One common use of PCBs was in transformers.

The production of PCB-containing capacitors and transformers ended in January 1979. However, the use of PCBs in some totally enclosed applications remains legal to this day. The life expectancy of capacitors and transformers is decades. In-place capacitors, transformers, and other PCB-containing equipment are still significant potential sources of PCBs to the environment. A USEPA voluntary transformer registration database showed significant ongoing use, almost 200,000 kg, in the San Francisco Bay Area (the entries in the database were reported between 1998 and 2001) (USEPA 2004).

Leakage from or improper handling of PCB-containing equipment over many decades has led to contamination of sites in the Bay-Delta watershed that persists today, and stormwater continues to wash contaminated soils from these sites into the Bay. Contaminated sites are present in the watershed and along the shoreline of the Bay. Remediation and control of PCB releases from these sites may help to achieve the loadings reductions necessary to attain the Bay's beneficial uses. In addition, implementation actions will likely need to address releases associated with widespread open-ended historical PCB uses.

The 1979 ban resulted from a growing appreciation of the health risks of PCBs. In spite of the fact that their use has been restricted for almost two decades, PCBs remain among the environmental contaminants of greatest concern because they are potent toxicants that are resistant to degradation and have a strong tendency to accumulate in biota. PCBs can cause toxic symptoms including developmental abnormalities and growth suppression, disruption of the endocrine system, impairment of immune function, and cancer. USEPA classifies PCBs as a probable human carcinogen. PCBs and other similar organochlorines reach higher concentrations in higher levels of aquatic food chains in a process known as "biomagnification." Consequently, predatory fish, birds, and mammals (including humans that consume fish) at the top of the food web are particularly vulnerable to the effects of PCB contamination (Figure 3).

## What is the Problem?

The Clean Water Act requires California and the federal government to adopt and enforce water quality standards to protect the Bay. The Basin Plan and the California Toxics Rule delineate these standards. The standards in-

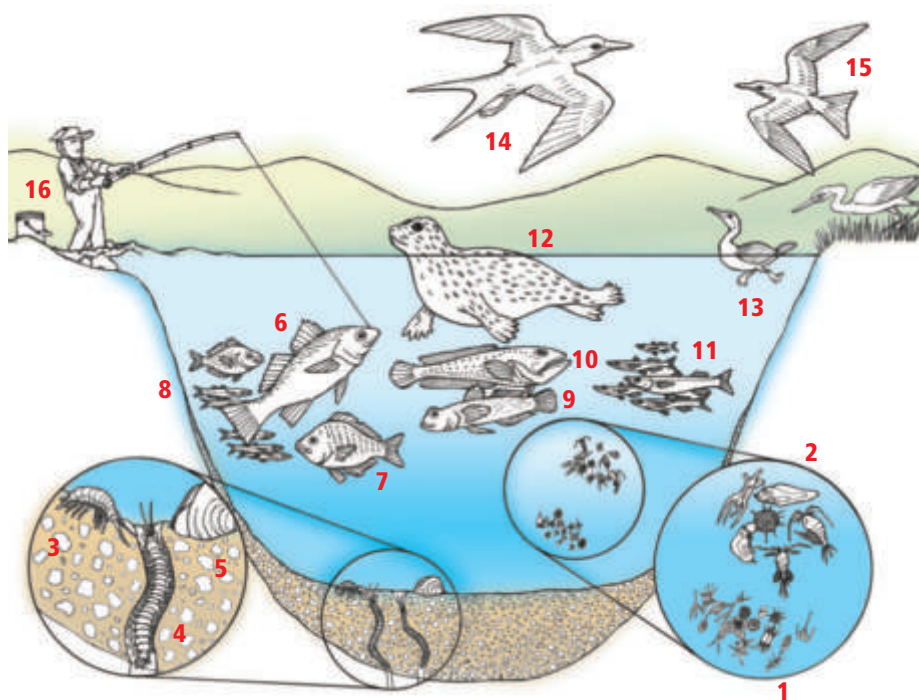
clude beneficial uses of the Bay, numeric and narrative water quality criteria to protect those uses, and provisions to enhance and protect existing water quality. Section 303(d) of the Clean Water Act requires states to compile a list of "impaired" water bodies that do not meet water quality standards (the "303(d) List"). All segments of San Francisco Bay appear on the 303(d) List because PCBs impair the Bay's established beneficial uses, including sport fishing, preservation of rare and endangered species, and protection of estuarine and wildlife habitat. PCBs in the Bay are considered a problem because they pose health risks to both humans and wildlife

## Human Health Concerns

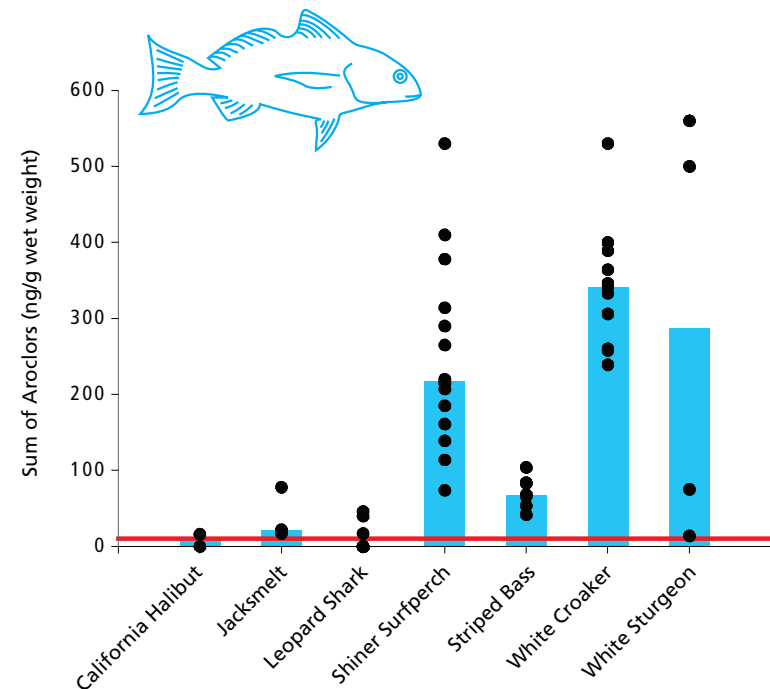
The use of the Bay for sport fishing is impaired, as indicated by the existence of a fish consumption advisory. The advisory was issued in 1994 by the California Office of Environmental Health Hazard Assessment (OEHHA) after a study that year found concentrations of mercury, PCBs, and other chemicals in popular sport fish species at levels that posed potential human health risks. PCB concentrations in sport fish were, along with mercury, a primary cause of the consumption advisory and the consequent classification of the Bay as an impaired water body. PCB concentrations in sport fish are therefore a fundamentally important index of PCB contamination in the Bay.

Sport fish monitoring in the Bay has been conducted on a three-year cycle since the initial effort in 1994. Sport fish sampling in later years has generally confirmed the 1994 findings, and, as a result, the OEHHA advisory remains in place. The advisory recommends a maximum consumption of two meals per month of Bay sport fish, with more restrictive limits (one meal per month) for women of child-bearing age and children. Fetuses and young children are most sensitive to the effects of PCBs, mercury, and other food web contaminants.

PCB concentrations in sport fish can be compared to a sport fish target of 10 ng/g (parts per billion) from the proposed TMDL. The most recent data (from 2003 – Davis *et al.* 2006) show that PCB concentrations vary among species (Figure 4). Two sport fish species (white croaker and shiner surfperch) are key indicators of PCB impairment because they accumulate relatively high concentrations and are commonly found in nearshore areas easily accessed by subsistence fishers. These high concentrations are largely a function of the relatively high fat content in these species. Median concentrations in these two species in the latest round of sampling in 2003 were 342 ng/g wet in white croaker and 217 ng/g wet in shiner surfperch, well over ten times higher than the 10 ng/g TMDL target.



**Figure 3. The Bay food web impacted by PCBs.** PCBs enter the food web primarily through accumulation by phytoplankton (1) at the base of the food web. PCB concentrations then increase with each step up the food web, in a process known as “biomagnification,” reaching maximum concentrations and posing the greatest health risks in species that consume Bay fish. Phytoplankton (1) are consumed by small animals including zooplankton (2) and invertebrates such as amphipods (3), worms (4), or clams (5). Invertebrates in the sediment also accumulate PCBs directly from sediment through ingestion of particles and from contact with sediment porewater. Fish consume the zooplankton and invertebrates and receive a higher dose of PCBs. People (16) and wildlife species consume the fish and receive an even higher dose. Wildlife consume smaller fish species such as yellowfin goby (9), plainfin midshipmen (10), and anchovy (11). People prefer larger species such as white croaker (6), shiner surfperch (7), and jacksmelt (8). The wildlife species most sensitive to PCB accumulation and effects include harbor seals (12), cormorants (13), Forster’s terns (14), and the endangered least tern (15).



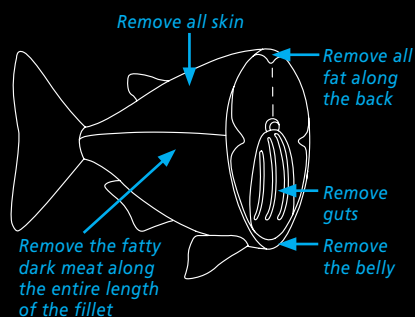
Footnote: PCB concentrations (as Aroclors) in San Francisco Bay sport fish, 2003. Bars show medians, points are individual samples representing composites of multiple fish. Line indicates TMDL target for sport fish of 10 ng/g.

**Figure 4. PCB concentrations in sport fish are, along with mercury, a primary cause of the consumption advisory for the Bay.** Two sport fish species (white croaker and shiner surfperch) are key indicators of PCB impairment because they accumulate relatively high concentrations and are commonly found in nearshore areas easily accessed by subsistence fishers. Median concentrations in these two species in the latest round of sampling in 2003 were 342 ng/g wet in white croaker and 217 ng/g wet in shiner surfperch, well over ten times higher than the 10 ng/g TMDL target for sport fish. Overall, in 2003, 44 of 51 measured samples (86%) for the species shown had concentrations higher than the screening value.

Other species with median concentrations consistently above the target across the four rounds of sampling were white sturgeon, striped bass, and jacksmelt. Overall, in 2003, 44 of 51 measured samples (86%) for the species shown in [Figure 4](#) had concentrations higher than the target. The data for white croaker indicate that approximately a 97% reduction in PCB concentrations will be needed to eliminate the impairment.

## Reducing Exposure Through Preparation and Cooking Techniques

In 1997, a RMP study found that removing skin from white croaker fillets substantially reduced concentrations of PCBs and other organic pollutants (Davis *et al.* 2002). The average percent reduction for PCBs was 39%, with a range of 11% to 53%. These reductions were associated with decreased amounts of fat in the fillets without skin. Fat content was reduced by an average of 33% in the fillets without skin.



Other cooking and preparation techniques can also reduce exposure to PCBs and other organic pollutants such as DDT, dioxins, and PBDEs. These include:

**Eat only fillet portions** - The fillet portions of fish are the safest parts to eat. Chemicals tend to be much higher in the guts and liver of fish. Do not eat these parts and do not use them to make sauces, stock, or chowder.

**Trim away fat** - Many chemicals, including DDT, PCBs, and dioxins, are stored in the fat. You can reduce your exposure to these chemicals by trimming fatty areas. Fat is located near the skin and along the back, belly, and lateral line.

**Cook so that fat drips off** - Bake, broil, steam, or grill fish on a rack so that the juices from the fat drip off during cooking. Throw out the juices. Deep frying in vegetable oil (not animal fats like butter) or poaching will also remove some of the fat, but discard the liquid after cooking. Chowders and stews are not advisable.

Fish consumption advisories and additional guidance on safe consumption of sport fish are available at the website of the California Office of Environmental Health Hazard Assessment: <http://www.oehha.ca.gov/fish.html>

## Wildlife Health Concerns

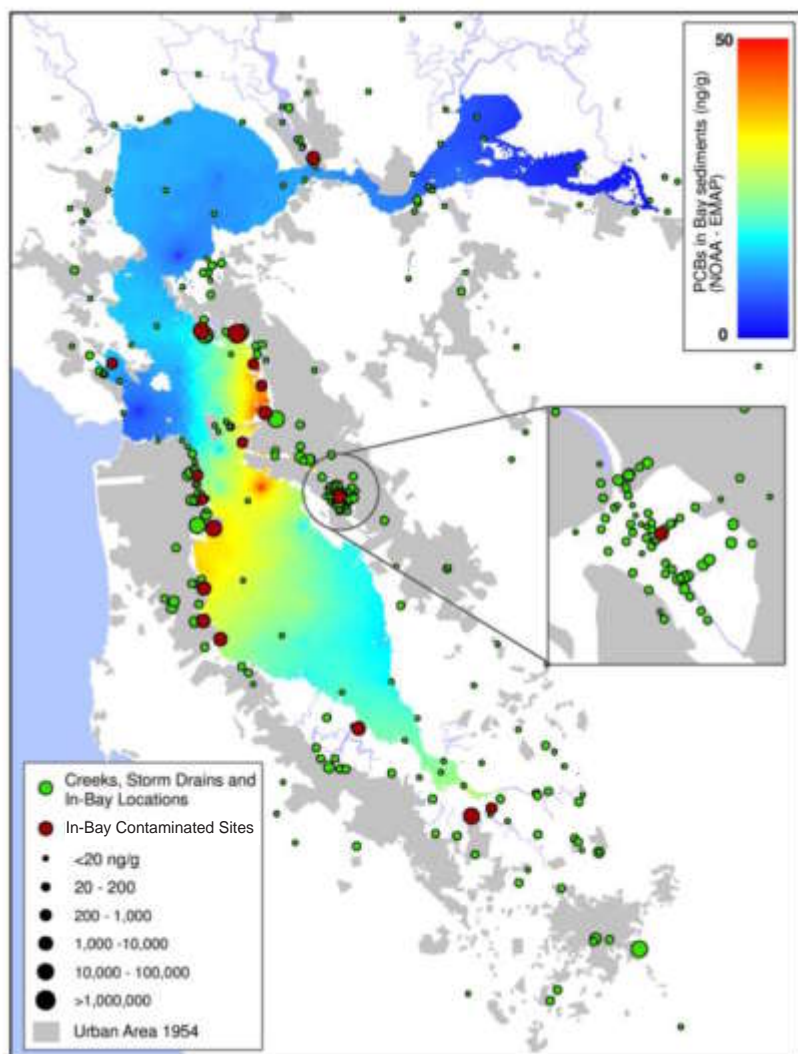
Several sources of information indicate that PCB concentrations in the Bay may be high enough to adversely affect wildlife, including rare and endangered species. Fish-eating species at the top of the food web face the greatest risks ([Figure 3](#)). Populations residing in highly contaminated sites also face relatively high risks. Studies of PCBs in eggs of the endangered California clapper rail, the endangered California least tern, and the double-crested cormorant have found concentrations that are near the threshold for embryo mortality. PCBs in harbor seals are also high enough that reproductive and immunological effects may be possible. The most intensive study of PCB effects in Bay fish was performed in the 1980s, and showed a correlation between PCB concentrations and survival of starry flounder embryos. A more recent study conducted from 1999 – 2001 found that early life stages of striped bass from the Sacramento River had developmental abnormalities that would result in reduced survival in the field, and these abnormalities appeared to be associated with elevated concentrations of PCBs and other pollutants.

PCB concentrations in some Bay wildlife species appear to be above or near thresholds for effects. Given the long-term general trend of slow decline in PCBs in the Bay, concentrations should gradually fall below these thresholds. However, a major uncertainty with regard to PCB effects on wildlife is the extent to which PCBs combine with other stressors, such as other contaminants, diseases, or food shortage, to impair sensitive life-history processes such as reproduction, development, sexual differentiation, and growth. It is possible that the effects of PCBs on wildlife, in combination with other stressors, may be significantly greater than currently realized.

## Spatial Patterns of Impairment

Concentrations of PCBs in surface sediments are the best indicator of the spatial distribution of PCB impairment in the Estuary. Extensive sediment sampling has been performed in the Bay Area over the past 25 years by the RMP and other programs, providing a high-resolution picture of the distribution of PCBs in sediments of the Bay and its local watersheds ([Figure 5](#)). PCB contamination in the Bay is primarily associated with urban areas along the shoreline. Numerous contaminated sites in the nearshore zone have been identified downstream of industrial areas. Creeks and storm drains upstream of the contaminated sites are similarly elevated. Contaminated sites along the western shoreline south of San Francisco and the eastern shoreline from Richmond through Oakland and south to San Leandro have resulted in elevated concentrations at a regional scale. Concentrations are also consistently elevated across a large portion of the water-





**Footnote:** Data compiled from RMP monitoring (e.g., SFEI 2002), the 2000 and 2001 NOAA-EMAP survey (USEPA, 2001), Hunt et al. (1998), Daum et al. (2000), KLI (2002, 2003), and Salop et al. (2002). Urban area in 1954 from the USGS Urban Dynamics Research Program (2000). In-Bay contaminated sites were identified by SFBWQCB (2004).

**Figure 5. Average PCB concentrations in Bay Area sediment.** PCB contamination in the Bay is primarily associated with urban areas along the shoreline. Numerous in-Bay contaminated sites in the nearshore zone have been identified downstream of industrial areas. Creeks and storm drains upstream of the contaminated sites are similarly elevated. Strong spatial gradients in PCB concentrations persist decades after the release of these chemicals to Bay Area waterways, illustrating the persistence and slow dispersion of PCBs from contaminated sites in the Bay and adjoining watersheds.

shed surrounding lower South Bay. Strong spatial gradients in PCB concentrations persist decades after the release of these chemicals to Bay Area waterways. These data illustrate the persistence and slow dispersion of PCBs from contaminated sites in the Bay and adjoining watersheds.

## Where are the PCBs Coming From?

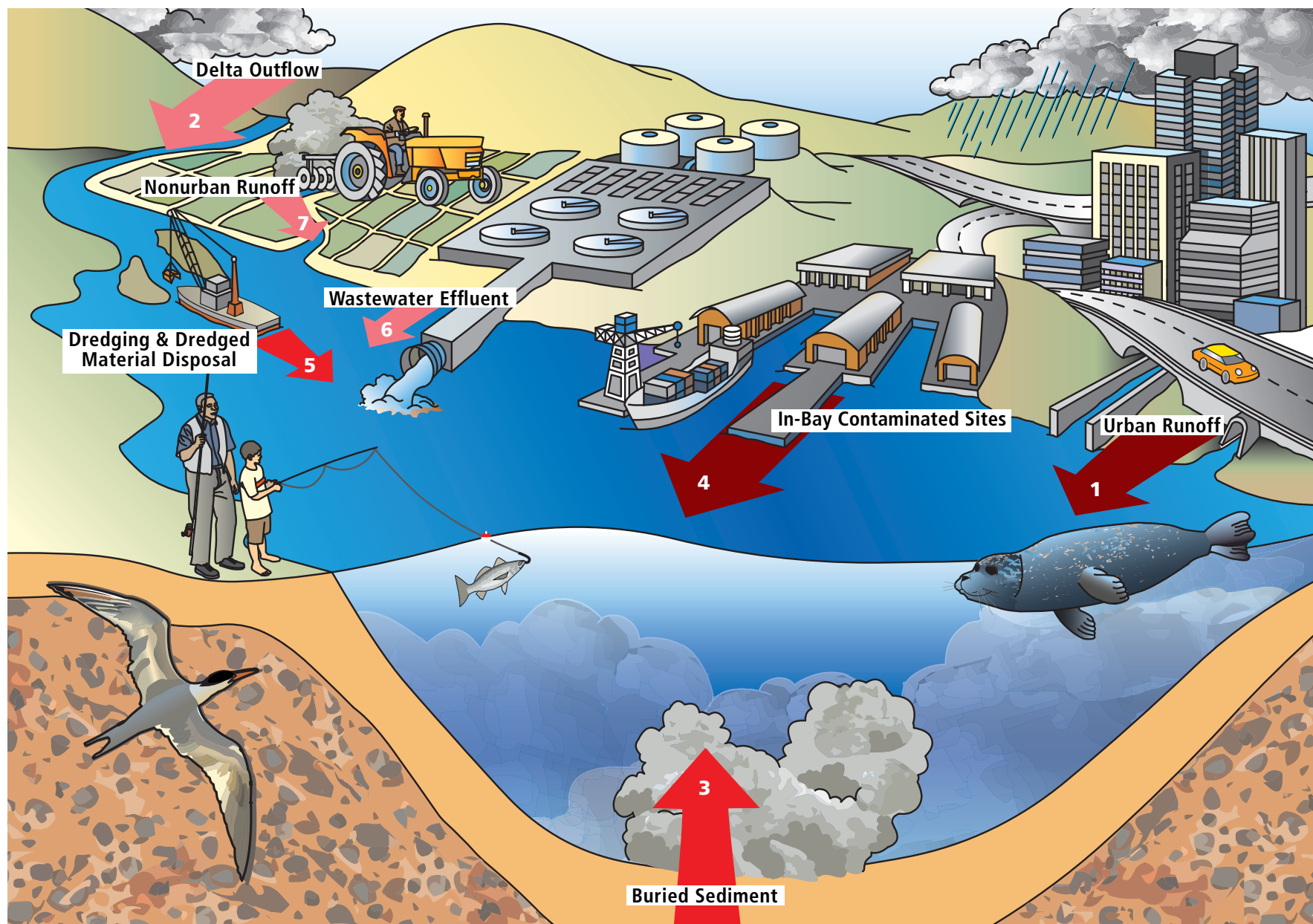
### Urban Runoff

Urban runoff from local watersheds is a significant pathway for PCB entry into the Bay (Figure 6). The mass of PCBs entering the Bay through this pathway is relatively large. In addition, PCBs from urban runoff enter the Bay in relatively concentrated streams that are probably trapped along the Bay margins, where they are more likely to contribute to food web contamination. The PCB TMDL is calling for relatively large reductions in loads from urban runoff.

Bay Area watersheds generally consist of a non-urban upper watershed that begins in the Coast Range hills surrounding the Bay and a highly urbanized lower watershed. PCBs are ubiquitous worldwide due to their capacity to enter the atmosphere, so small quantities are found throughout Bay Area watersheds. However, the lower, urbanized portions of the watersheds are where the activities associated with PCB usage and subsequent contamination were concentrated, and are where the PCBs present in urban runoff predominantly originate. Industrial sites where PCBs were used in electrical equipment or where such equipment was stored or salvaged are important sources of PCBs in urban runoff from the local watersheds. With each rainstorm, contaminated soils from these sites are gradually washing into creeks, storm drains, and the Bay.

A continuing study on the Guadalupe River has confirmed that urban runoff carries significant quantities of PCBs and other contaminants to the Bay (McKee et al. 2005). In water year 2003 (WY, October 2002 - September 2003) the estimated load of PCBs was 1.2 kg. In WY 2004 the estimated load was 0.7 kg. The Guadalupe River watershed encompasses 8% of the watershed area directly adjacent to the Bay, suggesting that, as a first approximation, the overall load of PCBs from local watersheds in 2003 and 2004 was in the range of 9 – 15 kg per year. How representative the Guadalupe River watershed is of Bay Area watersheds in general is an important information gap that could either increase or decrease the estimate of loading. An annual PCB load of 9 – 15 kg would be a significant input relative to both other inputs and the total estimated input to the Bay.





**Figure 6. PCB pathways to the Bay.** 1) urban runoff; 2) Delta outflow; 3) buried sediment; 4) in-Bay contaminated sites ; 5) dredging and dredged material disposal; 6) wastewater effluent; and 7) nonurban runoff. Not shown: atmospheric exchange. The size of each arrow indicates the relative magnitude of the load. The color of each arrow indicates how concentrated the input stream is (darker colors more concentrated). Urban runoff, Delta outflow, erosion of buried sediment, and in-Bay contaminated sites likely represent the largest pathways.

Contaminated sites in the watershed and contaminated creeks and storm drains are considered to be significant contributors to PCBs in urban runoff (see page 53). Other recently published information indicates that more diffuse watershed inputs from PCBs in sources like building sealants and fluorescent light ballasts may also be important. The relative importance of different PCB sources to urban runoff is one of the highest priority PCB information gaps.



Urban runoff is a significant pathway for PCB entry into the Bay

Proposed control measures specific to PCBs include cleanup of contaminated sites on land, in storm drains, and in the vicinity of storm drain outfalls, and capture, detention, and treatment of highly contaminated runoff. However, there is currently insufficient data to determine which approaches are most effective. Loads of PCBs and other contaminants are being reduced through continued implementation of urban runoff management practices and controls, such as vegetative buffers around paved surfaces, and street sweeping programs. Although it is known that these measures have an impact on contaminant loads, there is currently limited information that can be used to estimate the likelihood of success in achieving urban runoff load reductions. Expected trends in PCB loads from urban runoff with and without further management actions is a high priority information gap. A primary objective of a current \$1.3 million study is to evaluate the feasibility of achieving load reductions from urban runoff (McKee *et al.* 2006).

## Delta Outflow

Delta outflow is the primary source of freshwater input to the Bay. Delta outflow is also one of the most significant pathways of PCB input to the Bay (Figure 6). However, this relatively large mass input is due to a combination of very large flows with dilute concentrations of PCBs. Loads from the Delta may have a smaller impact on water quality than suggested by the large mass load. Sources of PCBs in Delta outflow are distributed throughout the Bay-Delta watershed, which includes approximately 37% of the land area of California.

A multi-year field study is currently underway to accurately measure PCB loads from Delta outflow (Leatherbarrow *et al.* 2005). Annual loads for 2002 and 2003 were 6.0 and 23 kg PCBs, respectively. Contaminant and sediment monitoring in this study occurred during years with relatively low flows. Similar to urban runoff, it is possible that PCB transport in years with higher flows and more intense storms would increase. Sampling conducted during higher flows in January 2006 (results not yet available) will help evaluate this hypothesis.

For two reasons, PCB inputs from Delta outflow may have less impact than those from urban runoff. First, the low concentration inputs from the Delta may dilute or bury more highly contaminated sediment in the Bay. Second, during large storms, when mass loads from the Delta are greatest, a significant portion of the PCB load may wash immediately through the Bay and out into the Pacific Ocean.

As with urban runoff, sediment PCB loads from the Central Valley are expected to be difficult to control. Nevertheless, the PCB concentration in suspended sediments coming from the Central Valley is greater than the sediment PCB target for the Bay. Eventual reductions of this load are expected as these concentrations on suspended sediment gradually attenuate over time.

## Erosion of Buried Sediment

PCBs mobilized from erosion of previously buried Bay sediments may have an impact on food web contamination that is comparable to urban runoff or Delta outflow (Figure 6). Bay sediments can be divided conceptually into two categories: active and buried. Active sediments are those that are at or near the surface and that are mixing into the water column, vertically mixing by physical or biological processes, and in contact with organisms that live in the sediment. Buried sediment is below the active layer, and out of circulation with the water column or food web. The vast majority of the total mass of PCBs in the Bay resides in these sediment layers. The top of the buried sediment layer is largely composed of sediment deposited during the era of the most severe contamination of the Bay in the 1950s and 1960s.

Recent studies have shown that erosion of buried sediment is occurring in large regions of the Bay. This is an unusual phenomenon for an estuary. In typical estuaries, existing sediments are buried as additional layers of sediment are deposited every year. The Bay, however, is experiencing a sediment deficit, largely due to reduced sediment inputs from the Central Valley. In the future, large-scale floodplain and wetland restoration projects in the Bay and its watershed are likely to further reduce the sediment supply to the Bay and increase the rate of erosion. This poses a significant problem with respect to recovery of the Bay from PCB contamination because the sediments being eroded and remobilized are from the relatively contaminated upper buried layer. Erosion of buried sediment has the same effect as other PCB inputs – increasing the mass of PCBs in circulation in the active sediment layer, the water column, and the food web, and delaying recovery of the Bay from PCB contamination.

Erosion of PCBs from buried sediment is a pathway that is not easily controlled. However, it is important to understand the magnitude of this pathway so that reasonable expectations for recovery can be established. The magnitude of this pathway is likely to be relatively large, and may become larger as the sediment deficit increases, but is not well quantified at present.

### In-Bay Contaminated Sites

Contaminated sites in the Bay are likely a major contributor of PCBs to the Bay food web (Figure 6). These contaminated sites are known to cause increased PCB bioaccumulation on a local scale, and are suspected to contribute to bioaccumulation on a regional scale. However, the relative contribution of contaminated sites to impairment is hard to quantify.



USS Atlanta at Hunter's Point Naval Shipyard, October 1964, while completing conversion to a weapons effects test ship. From the collection of the Naval Historical Center: [www.history.navy.mil/index.html](http://www.history.navy.mil/index.html)

Twenty locations around the edge of the Bay have been identified as contaminated sites. These sites are generally associated with runoff from industrial and military facilities. Some of the sites are Superfund sites (e.g., Hunter's Point Naval Shipyard and Seaplane Lagoon at the Alameda Naval Air Station). Organisms that dwell in the contaminated sediment (benthic organisms) and their predators have elevated tissue PCB concentrations at these sites (SFBRWQCB 2004). Contaminated sites may have a disproportionately large influence on food web contamination because the nearshore areas where they occur also serve as habitat for the sport fish species (white croaker and shiner surfperch) that accumulate high PCB concentrations.

Contaminated sites are a pathway that is relatively controllable. At some of the contaminated sites that have been identified, remedial investigations are already underway. Remedial actions are anticipated that will greatly reduce food web contamination at a local scale, and possibly accelerate recovery of the Bay at a regional scale. The major uncertainties associated with contaminated sites include the anticipated benefits of cleanup at the local and regional scales and the cost-effectiveness of various remediation options, such as removal, burial, or sequestration.

### Dredging and Dredged Material Disposal

In terms of the mass of PCBs involved, dredged material disposal in the Bay is a moderately significant pathway for PCB transport (Figure 6). However, this transport actually moves sediment from one location to another within the Bay, and does not increase the total mass in the ecosystem. Concern does exist over the localized impacts on PCB bioaccumulation near the disposal sites.

The average annual input of PCBs from disposal at in-Bay sites from 1998 to 2002 was 12 kg, a moderate amount relative to other pathways. It should also be noted that an average of 11 kg per year was removed from the Bay through disposal of dredged material in the ocean and at upland sites. The voluntary reduction of in-Bay sediment disposal put forth in the Long Term Management Strategy for the Disposal of Dredged Material in the San Francisco Bay Region (LTMS) Program would reduce the input of PCBs at in-Bay disposal sites. The LTMS seeks to reduce the total volume of in-Bay disposal to approximately 1,000,000 cubic yards per year by 2012 (see page 36).

Increased PCB accumulation in the local food webs around disposal sites may result from the dispersal of the dredged material on the surface sediment layer in the Bay. These increases may occur if the disposed dredged material has higher PCB concentrations than the sediment it is depositing on. However, the sediment released at in-Bay disposal sites is generally not highly contaminated. Dredged material disposal does not increase the mass of PCBs in the Bay, and therefore is not anticipated to contribute to delayed recovery of the ecosystem as a whole.

### Wastewater Effluent

There are 41 municipal and 27 industrial wastewater discharges in the San Francisco Bay region. Available data indicate that these wastewater discharges account for a small fraction of the total input of PCBs to the Bay (Figure 6). The current total annual loads from municipal and industrial dischargers are estimated at 2.3 and 0.012 kg/yr, respectively.

### Atmospheric Exchange

Since PCBs are somewhat volatile and tend to enter the atmosphere, atmospheric transport and deposition can be important processes. In San Francisco Bay, exchange between the water and the atmosphere results in an estimated net loss to the atmosphere of 7 kg/year.

## Recovery Forecasts

### Following a PCB Molecule

A typical PCB molecule enters the Bay from one of the many pathways described above, then becomes trapped in the ecosystem for decades. During its long residence in the Bay, the molecule will spend most of the time in the sediment, with brief episodes of suspension into the water column. PCBs mostly enter the Bay attached to sediment particles that settle out and enter the top layer of sediment on the bottom of the Bay (Figure 7). Waves driven by tides, winds, and storms sweep sediment up from the Bay floor and into the water column, and then the sediment settles back down, completing a recurring cycle of resuspension and deposition. Wave action and bioturbation cause mixing of the active sediment. The degree of mixing gradually diminishes at greater depths, until a point is reached at which sediments are out of reach of waves and bioturbation in the buried sediment layer. The mixing of PCBs into the vast pool of active sediment is one of the factors causing the Bay to respond so slowly to changes in loads.

Most PCB molecules end up eventually leaving the Bay through outflow to the ocean, volatilization to the atmosphere, burial in deep sediment, or metabolic degradation by bacteria (Figure 7). The amounts of PCBs that can be lost from the Bay each year through outflow, volatilization, burial, or degradation are small relative to the mass in the active sediment layer, and this is another factor that makes the Bay slow to recover from PCB contamination. The Bay is presently undergoing net erosion rather than burial, so the most important removal pathways for PCBs are outflow, degradation, and volatilization. Outflow of PCBs and sediment particles through the Golden Gate and degradation rates of PCBs under real-world estuarine conditions are both processes that are difficult to measure, for which information is lacking, and that have a large influence on the recovery of the Bay from PCB contamination.

### Predicting Recovery of the Bay

With estimates of the rates of all of these input, mixing, and removal processes it is possible to predict future trends in concentrations in the Bay. A simple mass budget model for PCBs in Bay water and sediment (Davis 2004, Davis *et al.* 2006) was developed as a first step toward creating this type of predictive capacity. This simple model was useful in illustrating some general concepts (Figure 8). First, the model predictions illustrate something that is evident from the limited data available on long-term trends – recovery from the current level of PCB contamination appears likely to take several decades. PCB concentrations in

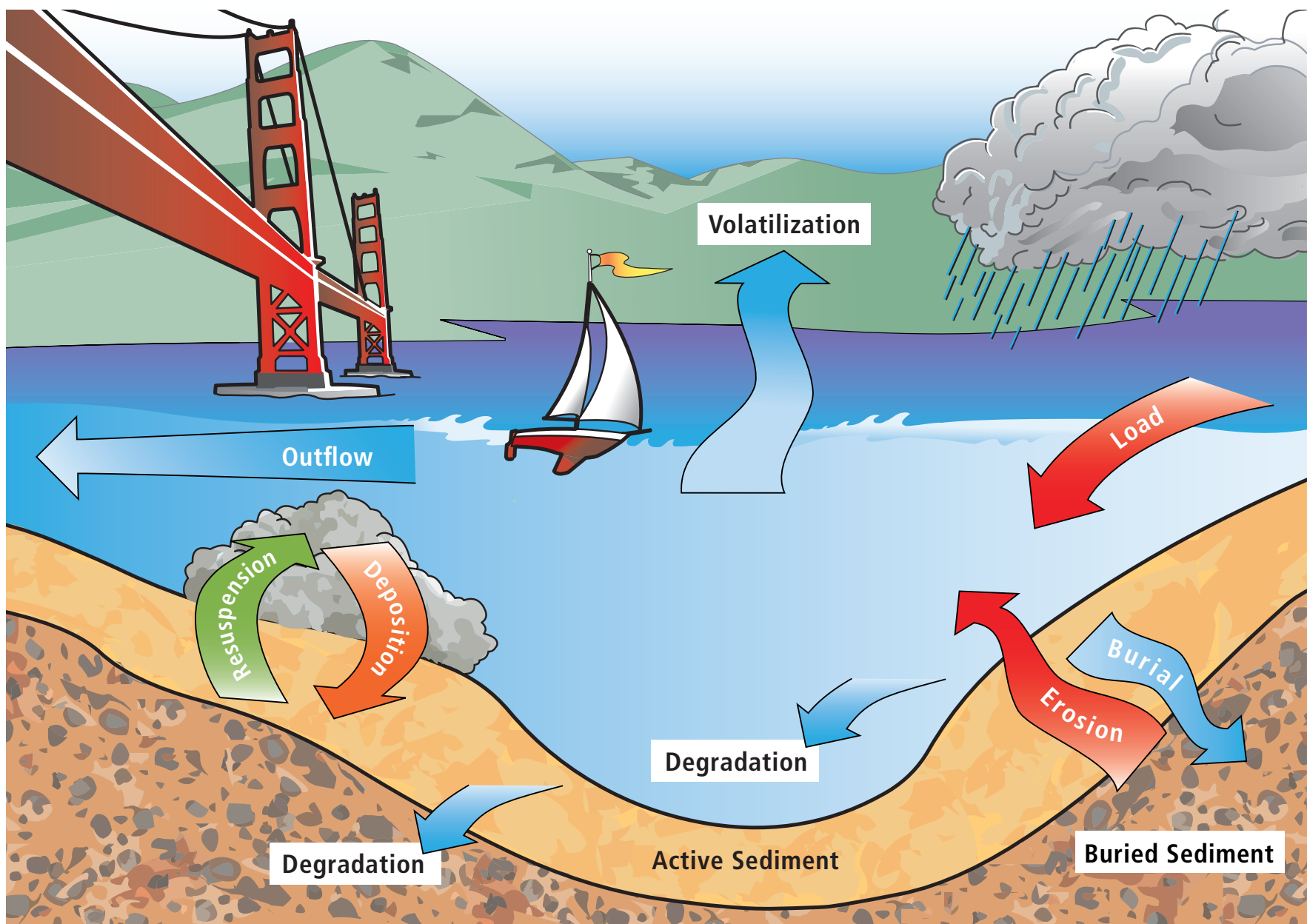
some sport fish are more than 10 times higher than the TMDL target, and in the slowly responding Bay ecosystem, a reduction of more than 90% is going to take a significant amount of time.

Second, the model identified the parameters that have the largest influence on the rate of recovery – these include degradation rate, partition coefficient, outflow, average PCB concentration in sediment, and depth of the active sediment layer. Obtaining better information on these parameters is a priority for future studies.

Third, the model provided a preliminary evaluation of different management and loading scenarios (Figure 8). Each curve shown in Figure 8 should be considered an uncertain approximation of the actual rates of decline that will occur. If the loading of PCBs to the Bay could be completely eliminated, this model predicted that the total mass of PCBs in the Bay would drop to 10% of the present value in about 35 years. The estimate for this scenario underscores the sluggish responsiveness of the Bay to reductions in inputs. The model also indicated that sustained annual loads on the order of tens of kilograms could significantly delay recovery. For example, a sustained annual load of 10 kg per year would increase the estimated amount of time needed to reach the 10% level to about 45 years. Sustained loading of 20 kg/year would prevent the total PCB mass in the Bay from ever dropping below 10% of the present mass.

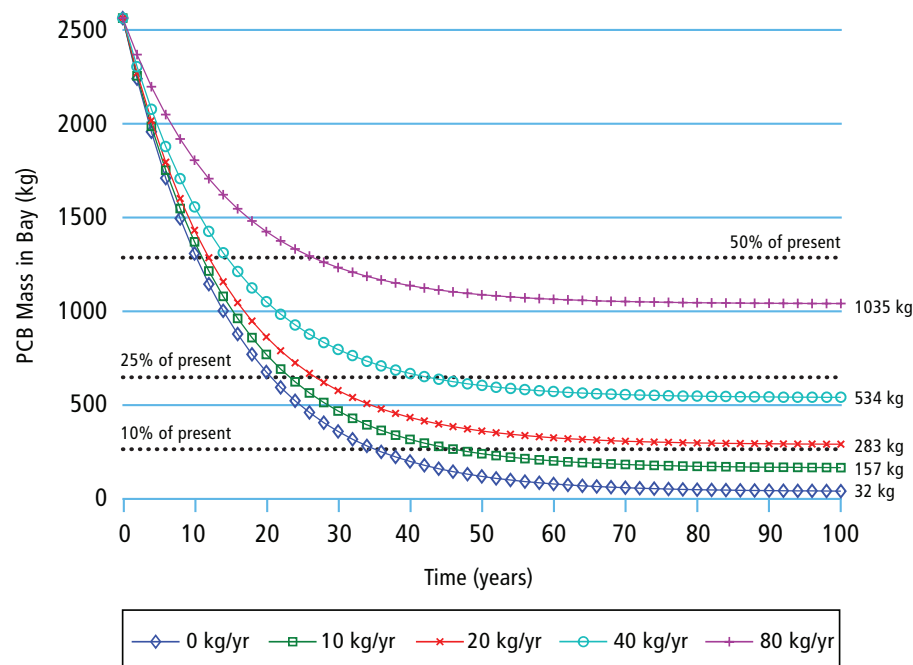
The attention of water quality managers and scientists in the region has now shifted to the next generation of fate model for the Bay. In work funded by the RMP and the Clean Estuary Partnership (CEP), a more sophisticated mass budget model is in development. This model incorporates more realistic treatments of loads to the Bay, mixing down into the sediment at the bottom of the Bay, the varying properties of different regions of the Bay, and a quantification of the uncertainty of the model estimates. This work will represent a major step forward in modeling the fate of persistent, particle-associated contaminants in the Bay in support of the RMP and total maximum daily load development and implementation.





**Figure 7. PCB cycling in Bay water and sediment.** A typical PCB molecule enters the Bay from one of the many pathways described above, then becomes trapped in the ecosystem for decades. During its long residence in the Bay, the molecule will spend most of the time in the active sediment layer, with brief episodes of suspension into the water column. Most PCB molecules end up eventually leaving the Bay through outflow to the ocean, volatilization to the atmosphere, or degradation by bacteria. The rates of these processes govern the potential rate of recovery of the Bay. Burial is not a pathway for net loss over the long term, as the Bay is currently undergoing net erosion.






Footnote: Inset box indicates loading rates, which are assumed constant over the 100 year period. Values to the right of the graph indicate masses for each scenario at the end of the 100 year simulation.

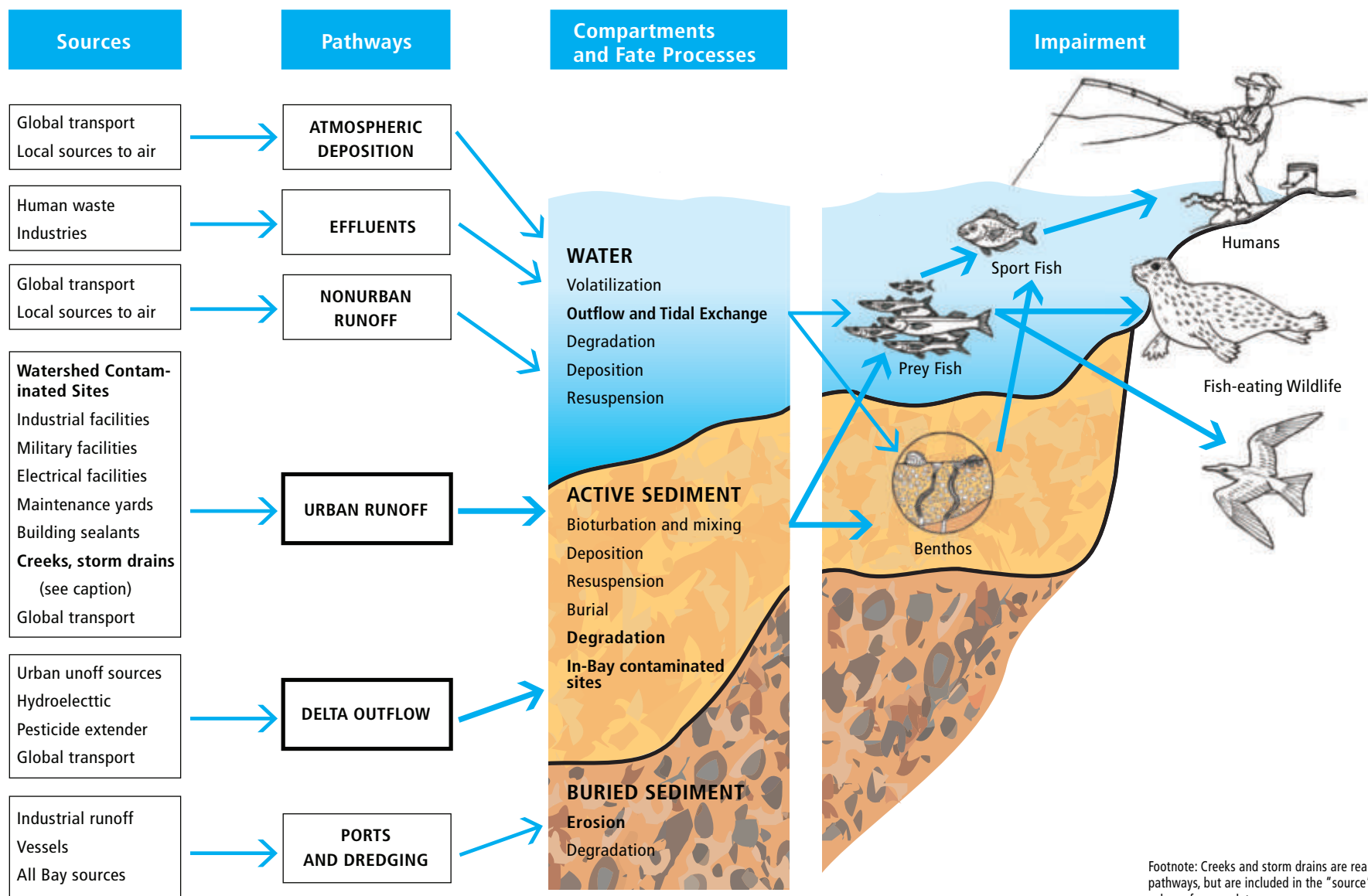
**Figure 8. Predicted masses of PCBs in San Francisco Bay in the next 100 years with varying amounts of external loading.** A simple mass budget model for PCBs in Bay water and sediment was useful in illustrating some general concepts. Recovery from the current level of PCB contamination appears likely to take several decades. PCB concentrations in some sport fish are more than 10 times higher than the TMDL target, and in the slowly responding Bay ecosystem a reduction of more than 90% is going to take a significant amount of time. The model also indicated that sustained annual loads on the order of tens of kilograms could significantly delay recovery. Based on field studies, current loads appear to be in the range of 40 to 80 kg per year.

## Next Steps

Priorities for the monitoring and management of PCBs can be illustrated with a conceptual model linking sources, pathways, Bay compartments and fate processes, and impairment ([Figure 9](#)). The major pathways of continuing PCB loading to the Bay are urban runoff and Delta outflow, with in-Bay contaminated sites and the process of erosion of buried sediment also contributing significantly. Opportunities for significant reduction of PCB loading and accumulation in the Bay food web are greatest for urban runoff and contaminated sites where deposits of PCBs are concentrated and most amenable to cleanup. Investigations like the one performed in the Ettie Street watershed in Oakland ([see page 53](#)) have been valuable in identifying the sources of PCBs to urban runoff and highly contaminated areas where cleanup can be most cost-effective. A sound understanding of the processes that link sources to accumulation in the food web will help in selecting cleanup actions that will yield the greatest reduction in accumulation in the food web. Monitoring of the effectiveness of cleanup actions on local and regional scales will be essential to adaptive management of the PCB problem.

## A Lesson Learned?

Persistent, particle-associated pollutants in the San Francisco Bay-Delta watershed are slowly transported from their sites of origin through storm drains, creeks, and rivers toward the Bay in a recurring cycle of mobilization, deposition, and resuspension. Patterns of PCB, mercury, and lead contamination in the watershed indicate that the timescale for this process is decades or centuries. Once these polluted particles wash into San Francisco Bay, especially the South Bay, they become mixed into the bedded sediment and trapped in the ecosystem for many more decades, allowing the pollutants to seep into the base of the food web and become concentrated in sensitive life stages of humans and wildlife. The slow release of pollutants from the watershed and the slow response of the Bay to changes in inputs combine to make the Bay very slow to recover from pollution of the watershed. The history of PCB contamination in the Bay underscores the importance of preventing persistent, particle-associated pollutants from entering this sensitive Bay-watershed system. 



**Figure 9. Conceptual relationships of important PCB sources, pathways, compartments and fate processes, and impairment.** Bold text and arrows indicate the most critical elements. Opportunities for significant reduction of PCB loading and accumulation in the Bay food web are greatest for urban runoff and in-Bay contaminated sites where deposits of PCBs are concentrated and most amenable to cleanup. A sound understanding of the processes that link sources to accumulation in the food web will help in selecting cleanup actions that will yield the greatest reduction in accumulation in the food web. Monitoring of the effectiveness of cleanup actions on the local scale and of impairment at the regional scale will be essential to adaptive management of the PCB problem.



# PCBs in Urban Watersheds—A Challenge for TMDL Implementation

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## Key Points

- Recent investigations by Bay Area stormwater management agencies have greatly advanced our conceptual understanding of the distribution of PCBs in urban watersheds
- Areas with relatively elevated levels of PCBs were identified in surveys of sediment collected from urban area stormwater conveyances, and further case studies were conducted in some of these areas to attempt to identify PCB sources
- During source investigation studies conducted in the Ettie Street watershed in west Oakland, a coordinated sampling and inspection program was able to track the trail upstream to specific properties with elevated PCB concentrations
- A follow-up Ettie Street project is developing a model for how municipalities can work with local stakeholders, landowners, and local, state, and federal agencies to clean up source properties and thereby potentially reduce loads of PCBs to the Bay



## PCBs at the Crossroads of the Bay Area

West Oakland has long been at the crossroads of the Bay Area, from its early days as the terminus for the first transcontinental railroad to its present situation neighboring the Port of Oakland and the Bay Bridge's eastern approach. To address flooding problems in this low-lying area, the Ettie Street Pump Station was constructed in 1954, at that time the largest such facility on the West Coast. In 2000 and 2001, a Bay Area-wide sampling program found sediments with elevated concentrations of PCBs within multiple watersheds that drain to the Bay, including the Ettie Street Pump Station watershed. This finding led to a more detailed investigation of the sources of PCBs in the 1000-plus acre catchment that drains into the Station. These studies have contributed greatly to our evolving understanding of how PCBs and other pollutants of concern reach the Bay. Lessons learned from this investigation and partnerships formed through its implementation hold promise for assisting future PCB source identification and cleanup efforts.

## Reducing PCB Loads in Stormwater

Bay Area stormwater programs have been working with the San Francisco Bay Regional Water Quality Control Board (Water Board) to improve our understanding of PCB occurrence in local watersheds and develop effective strategies to control ongoing discharges to the Bay. PCB concentrations in the Estuary ecosystem continue to pose risks to human and wildlife health despite the federal ban on the sale and production of PCBs in 1979 (see page 40). Continuing inputs of PCBs to the Bay appear to be an important factor contributing to the persistence of PCBs in the Bay. The Total Maximum Daily Load (TMDL) for PCBs in San Francisco Bay (SFRWQCB 2004) proposes a 38 kg reduction in the annual load of PCBs from urban runoff, or a 95% reduction from the existing estimated annual load of 40 kg. An initial predictive model for PCBs in the Bay (Davis *et al.* 2006) suggests that continuing inputs on the order of 20 kg/yr could delay recovery of the Bay by decades. While future research is expected to resolve some of the uncertainties in this simple model, stormwater programs are working on strategies for addressing the identified TMDL load reduction needs.

Two primary options for implementing stormwater load reductions are *source control*, in which sources of PCBs are identified and cleaned up before they reach conveyances that connect to the Bay, and *treatment control*, in which structures or landscape features remove pollutants from the conveyance pathway before reaching receiving waters. During the past several years, Bay Area stormwater agencies have conducted a series of investigations that have greatly advanced our conceptual understanding of the abundance and distribution of PCBs in our urban watersheds. The results of these investigations suggest that areas with relatively elevated concentrations of PCBs remain, and that focusing cleanup efforts on these areas may be one cost-effective approach to reducing PCB loads to the Bay.



The Ettie Street Pump Station.

Relatively elevated concentrations of PCBs remain in our urban watersheds - focusing cleanup efforts on these areas may be one cost-effective approach to reducing PCB loads to the Bay

## Legacy PCBs in the Landscape

Growing concern about PCBs in the Bay in the late 1990s led to the formation of a RMP work group – the Chlorinated Hydrocarbon Workgroup (SFEI 1999) – to consider how regional monitoring could be used to improve our understanding of sources of PCBs and other chlorinated hydrocarbons. As part of the group's deliberations, two hypotheses were proposed regarding current loadings of PCBs to the Bay: (1) that PCBs discharged from our watersheds originate mainly from diffuse sources such as atmospheric deposition; and (2) an alternative hypothesis that discrete sources of PCBs that are possibly controllable still exist in certain watersheds. If the second hypothesis is true, greater opportunities will exist for cost-effective control of loads as part of the TMDL implementation process.

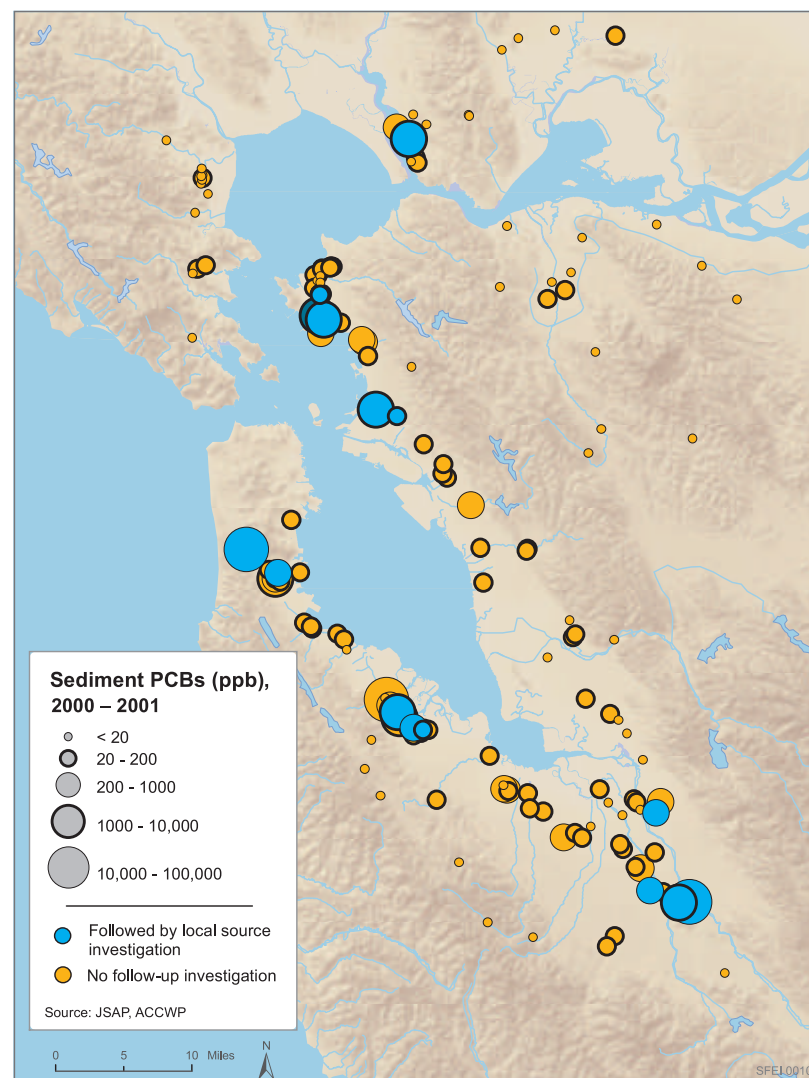
One way to test these hypotheses is to look at the distribution of PCBs in sediments from stormwater conveyances. If PCB sources are primarily diffuse throughout the region, then the expected outcome would be that sediments from watersheds of varying sizes and land use characteristics would show fairly uniform concentrations. If large variations in concentrations were observed, these findings would be more consistent with the hypothesis that discrete PCB sources remain in certain locations. In 2000 and 2001, stormwater management agencies implemented two related investigations that surveyed PCB concentrations in bottom sediments collected in creeks, flood control channels, and storm drains within a number of Bay Area watersheds:



- The Joint Stormwater Agency Project (JSAP), a collaborative effort of the Contra Costa County, Fairfield-Suisun, Marin County, San Mateo County, Santa Clara County, and Vallejo stormwater management agencies. This study focused on sampling engineered storm drain facilities above tidal influence throughout urbanized watersheds.
- The Alameda Countywide Clean Water Program (ACCWP). This effort sampled bottom sediments above tidal influence at the base of County watersheds, in waterways that drain the majority of Alameda County.

While the majority of Alameda County watersheds appeared to have sediments with relatively low PCB concentrations, several watersheds contained sediments with elevated concentrations (Salop *et al.* 2002a). The JSAP (KLI and EOA 2002) also found that concentrations were highly variable in urban areas, ranging from below limits of detection to 27,000 ng/g (parts per billion) (Figure 1). In a few instances concentrations were detected that were 1,000 – 10,000 times higher than Bay sediment samples measured by the RMP; one of these occurred in the Ettie Street watershed in northwest Oakland. These results supported the hypothesis that certain watersheds potentially contain important ongoing sources of PCBs to the Bay.

But where were the detected PCBs coming from? And if sources could be identified, were they controllable? Stormwater programs used results of these sediment surveys to set priorities for focused case studies investigating potential sources of PCBs. From 2001 to 2003, BASMAA member agencies conducted 17 different source investigation projects in areas where the initial JSAP or ACCWP sediment surveys found elevated concentrations of PCBs (Figure 1 and Sidebar page 56). The most extensive of the investigations performed to date is a series of studies in the Ettie Street Pump Station watershed, a mixed use watershed that is the most industrialized of those sampled by the ACCWP. This watershed was initially targeted for further investigation by the ACCWP because of its elevated concentration of PCBs relative to other Alameda County watersheds sampled. The investigation has expanded to include other partners and follow-up on progress made. The findings from this investigation illustrate some of the lessons and uncertainties of the source control approach.



**Figure 1.** In 2000 and 2001, stormwater management agencies conducted baseline surveys of PCB concentrations in sediments collected in Bay Area creeks, flood control channels, and storm drains. High concentrations observed in some locations supported the hypothesis that certain watersheds potentially contain important ongoing sources of PCBs to the Bay. From 2001 to 2003, source investigations at the contaminated locations provided confirmation and more detailed information on the extent of the contamination.



## Identifying Sources of PCBs via Case Studies in Urban Drainages

In addition to the Ettie Street investigations, other less extensive but important studies have been conducted in several Bay Area cities, including San Jose, South San Francisco, Richmond, San Carlos, Redwood City, San Pablo, and Vallejo. These studies developed methods to identify sources of PCBs within contaminated drainages. The studies generally included historical and current land use research, identification of known PCB use or release sites within the study drainage, additional sediment sampling, and analysis of PCB congener patterns. The results of the studies varied widely.

- Some investigations did not repeat the findings of elevated PCB concentrations from the regional surveys. For example, PCB concentrations at the industrial Monterey Highway site in San Jose were 90% lower in the follow-up case study.
- Some investigations confirmed regional survey results of elevated concentrations of PCBs, but were unable to identify suspected PCB sources. For example, investigations within a primarily residential area in the City of Vallejo found concentrations of PCBs in sediments up to 1700 ng/g (ppb), but source properties could not be identified.
- In other cases, the investigations revealed properties that are suspected PCB source areas and potential responsible parties. For example, PCBs were detected at concentrations up to 11,500 ppb in sediments from the Pulgas Creek Pump Station drainage, located in an industrial part of San Carlos. Two potential sources of PCBs were identified: an electrical substation and a soil and groundwater contamination cleanup site.
- Similarly, relatively elevated concentrations of PCBs (as high as about 20,000 ppb) were consistently found in sediments collected from the storm drain line beneath Leo Avenue in an industrial part of San Jose. The spatial distribution of PCB concentrations coupled with an analysis of PCB homolog patterns suggested that a specific property adjacent to Leo Avenue was a major source of PCB-containing sediments.

The PCB case studies have shown promise for identifying suspect source areas and potential responsible parties, but have also revealed that finding PCB sources is often a considerable challenge. Identifying PCB sources will require very intensive investigations such as those conducted around the Ettie Street Pump Station.





## Following the Trail

The Ettie Street Pump Station drains a mixed land-use section of west Oakland that extends south and east into downtown Oakland and discharges its runoff into the Bay ([Figure 2](#)). The areas closest to the Pump Station are mainly

mixed residential and industrial, passing through more commercial areas, and transitioning to mainly residential areas farther upstream. The storm drain system of the watershed is underground for its full extent.

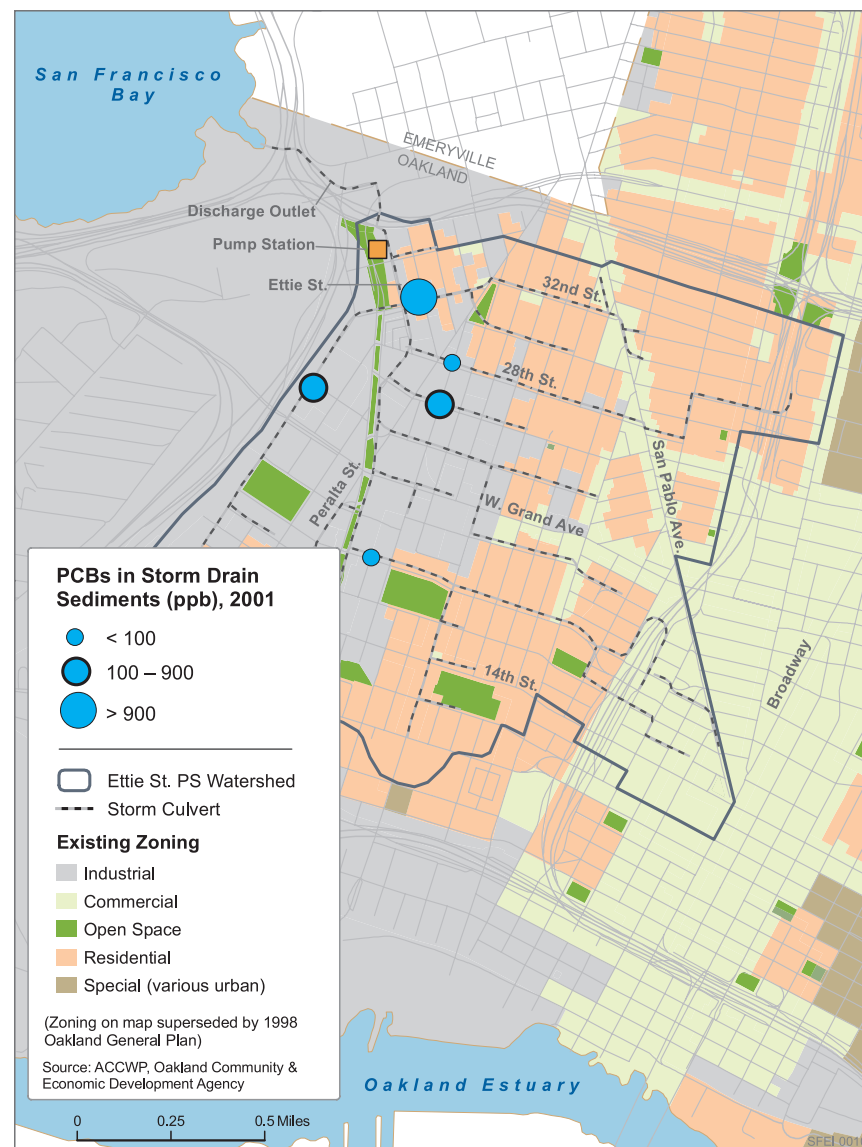
In 2001, the Alameda Countywide Clean Water Program used the Ettie Street watershed to test a pilot methodology for identifying potential source areas of pollutants accumulating at the Pump Station

In 2001, the ACCWP used the Ettie Street watershed to test a pilot methodology for identifying potential source areas of pollutants accumulating at the Pump Station. The first phase of the investigation sampled the five main storm drain lines that drain to the Pump Station. Although detectable concentrations

of PCBs were found at or near the base of all five catchments, the northernmost catchment was selected for further study based upon the magnitude of PCB concentrations found ([Figure 2](#)).

In this catchment, targeted sampling was conducted on sediments accumulating within 39 stormdrain inlets ([Figure 3](#)). Based upon PCB concentrations and comparisons of congener patterns to those of downstream sediments, Salop *et al.* (2002b) identified multiple small areas within the catchment that appeared to be associated with potentially important sources of PCBs ([Figure 4](#)).

Source identification efforts were facilitated by several features of the watershed: collection of all runoff at the Pump Station, forebays acting as sediment-accumulation traps within the Pump Station itself, and numerous local sediment accumulation points throughout the watershed in main drainage culverts and in older, catch-basin type inlets at street intersections. Some watersheds of interest lack such features, and therefore are not as conducive to performing this type of source identification work. However, the watershed is likely representative of other older industrial mixed-use watersheds in that there are likely to be multiple source areas discharging PCBs to stormwater conveyances at different concentrations.



**Figure 2.** The most extensive of the source investigations performed to date is a series of studies in the Ettie Street Pump Station watershed in west Oakland. The first phase of the investigation sampled the five main storm drain lines that drain to the Pump Station. The northernmost catchment was selected for further study based upon the magnitude of PCB concentrations.



Photo courtesy of Steve Miller

**Figure 3.** Further investigation of the northernmost subcatchment of the Ettie Street watershed included sampling of 39 storm drain inlets associated with potentially important sources of PCBs. Sampling of one of the inlets is shown here.



**Figure 4.** Multiple small areas within the northernmost subcatchment appeared to be associated with potentially important sources of PCBs. Sites with high PCB concentrations were clustered together in areas with similar land use.

## Identifying Sources

In 2002 the City of Oakland was awarded a Proposition 13 grant from the State Water Resources Control Board for a PCB Abatement Project focused on finding and abating PCB-containing sediments and sources in the Ettie Street Pump Station watershed. Another goal of this Project, scheduled for completion in late 2006, is to develop a model for how municipal staff can work with local stakeholders, landowners, and local, state, and federal agency staff to clean up source properties and reduce loads to the Bay.

**The PCB Abatement Project has piloted several innovative techniques for identifying specific properties acting as sources of PCBs to the pump station**

The PCB Abatement Project has piloted several innovative techniques for identifying specific properties acting as sources of PCBs to the Pump Station. Various databases, agency files, and other information sources were reviewed in an attempt to identify potential source properties out of more than 1700 businesses located in the watershed (Kleinfelder 2005). City inspectors combined this background research with driving and walking surveys of the entire watershed, using a checklist of attributes associated with past or current use of PCBs to identify potential source properties (see Sidebar).

City inspectors next conducted modified stormwater inspections within 123 properties identified through the database reviews and surveys. Based on the results of these inspections, the City selected candidate sites in the public right-of-way for follow-up sampling. Properties were characterized as high, medium, or low priority for sampling based upon past and present history of PCB spills or uses, as well as site characteristics or management practices that increased the likelihood of onsite pollutants entering stormwater (Salop 2004). This approach led to one immediate success: a 55-gallon barrel labeled as containing PCBs was found, along with other unlabeled barrels, in the yard of a current asbestos abatement business (Figure 5). The exact contents of this barrel are unknown, but assuming it was full and labeled accurately, proper disposal may have isolated up to 300 kg of PCBs. This mass would be equivalent to over ten percent of the estimated mass of PCBs present in the surface sediment layer of the entire Bay (Davis 2004), and nearly ten times the current estimate of annual stormwater loads of PCBs to the Bay (RWQCB 2004).



*Photo courtesy of Trish Eliasson*

**Figure 5.** Through background research and inspections, City inspectors were able to identify properties with a high potential as a PCB source. One of the successes was the discovery of a property with a 55-gallon barrel labeled as containing PCBs. If the contents of a barrel like this one were to enter the Bay through accidental or intentional dumping, the mass of added PCBs could be enough to delay recovery for many decades.

High priority uses or activities associated with PCBs, from checklist for site screening in the PCB Abatement Project in the Ettie Street Pump Station watershed (Salop 2004)

- Manufacture or handling of electrical applications  
(transformers, appliances, televisions, fluorescent light ballast, motors, etc.)
- Hydraulic fluids  
(lifts, die-casting machinery, etc.)
- Plasticizers  
(sealants, caulk, PVC, polyurethanes, polycarbonates, etc.)
- Drum cleaning/recycling\*
- Auto recycling/scrap
- Outdoor burning or combustion\*
- Miscellaneous  
(coatings, printing inks, pesticides)

\* indicates potential to cause dioxin-like compounds.



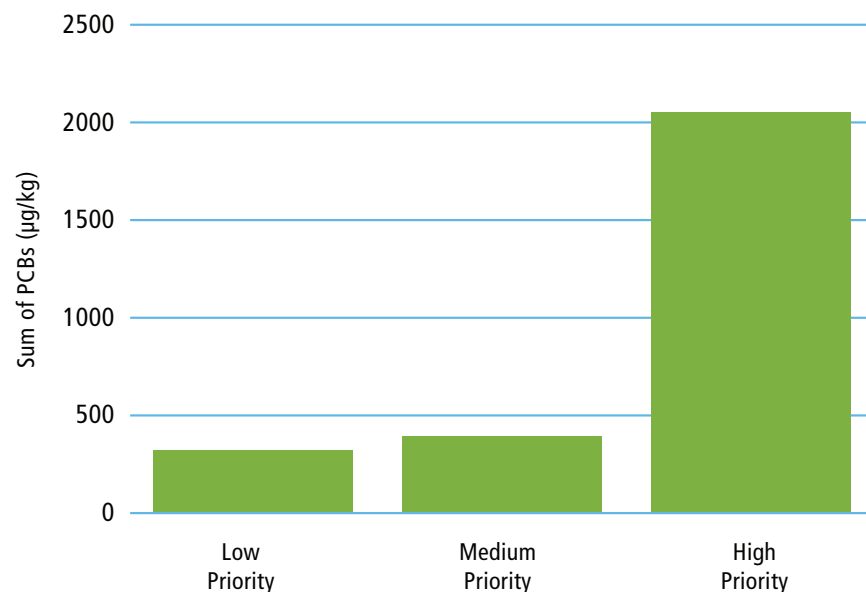


Sediments were then sampled from public rights-of-way at points where they were likely to have been washed from high priority properties. Results for these high priority samples ranged from 23 parts per billion (ppb) to over 31,000 ppb, with the maximum concentration found adjacent to the above-mentioned asbestos abatement business (Figure 6). Of the 41 samples collected at 37 high priority sites, 25 exceeded the Water Board's residential Environmental Screening Level (ESL) of 220 ppb, and 33 exceeded the California Department of Toxic Substance Control's California Human Health Screening Level (CHHSL) of 89 ppb (Kleinfelder 2005).



Transferring sediment into jars to be shipped to the analytical laboratories.  
Photo courtesy of Paul Salop.

The next phase of the PCB Abatement Project included sampling of sediments collected from 19 private properties (18 industrial sites and one residential site), ranked as high priority potential sources through the right-of-way sampling. Sampling was conducted through the City's annual Certified Unified Program Agency, the local agency certified by California EPA to manage various programs related to control of hazardous materials. Thirteen of the 25 total samples collected exceeded an industrial soil ESL of 740 ppb. A maximum concentration of over 93,000 ppb was found at a marble cutting facility on a property that had previously been involved with disposal of PCB-containing waste (Kleinfelder 2006). This property was one of several at which sediment PCBs were at least 10 times higher than concentrations in the downstream right-of-way.



Footnote: Bars indicate averages.

## Adaptive Management

In addition to the high priority sites sampled through the PCB Abatement Grant Project, in 2005 the ACCWP funded sampling of sixteen additional medium or low priority right-of-way sites as a check on the effectiveness of the prioritization scheme. Although high priority locations had higher concentrations than low or medium priority sites, there was no statistically significant difference between

**Figure 6.** The PCB Abatement Project then sampled sediments from public rights-of-way at points where they were likely to have been washed from high priority properties. Results for these high priority locations ranged from 23 parts per billion (ppb, µg/kg) to over 31,000 ppb. High priority locations had much higher average concentrations than low or medium priority locations.



sites characterized as high versus medium-to-low priority. However, these analyses did point out potential modifications to the prioritization scheme that could change this outcome in future investigations. For example, vacant lots with no indication of previous heavy industrial uses, considered high priority during this effort, were generally not associated with elevated concentrations and may be considered a lower priority for future sampling efforts.

Related concerns for potential direct human exposure in the urban landscape and a request by the Water Board Toxics Cleanup Division led to a related City investigation in 2005 in order to more fully test the effectiveness of the prioritization process. In this investigation, 18 right-of-way sites spread throughout the watershed were identified for sampling and analysis through a randomized selection process. The results of this investigation, when compared with the previous targeted sampling, strongly suggest that the private properties were the source of the PCBs in the right-of-way. For example, an upper bound value for the randomized right-of-way sampling was 680 ppb, compared to 2,500 ppb for the targeted right-of-way sampling and 14,000 ppb for the private property samples.

The elevated concentrations observed in these studies have caused PCB Abatement Project managers to increase their focus on cleaning up identified source areas. As part of this Project, the City initiated pilot abatement efforts in public rights-of-way during spring 2006. The City also has begun the outreach portion of the Project to share its findings and planned activities with local residents and business owners. Additionally, ongoing coordination between USEPA, the California Department of Toxic Substances Control (DTSC), the Water Board, City staff, and individual private property owners is facilitating development and implementation of an abatement program for identified source properties. The City is seeking additional funding to continue abatement work and post-abatement monitoring to gauge effectiveness.

**The elevated concentrations observed in these studies have caused PCB Abatement Project managers to increase their focus on cleaning up identified source areas**



*Inside the Ettie Street Pump Station. Photo courtesy of Applied Marine Sciences.*

One question yet to be answered is how the abatement activities in this Project will affect loadings to the Bay. The actual amount of PCB mass that will be removed in the abatement process is not well understood. It is also unclear how much of the PCB mass that is removed from the right-of-way areas, and potentially the private properties, would have actually made it to the Bay. New methods for understanding the mass of PCBs intercepted through abatement activities will need to be developed as abatement activities evolve.

## Challenges Ahead

Based on investigations conducted to date, it appears that some, mainly older industrial, watersheds in our region contain relatively large masses of PCBs, and effective isolation or removal of soils and/or sediments with PCBs in these priority watersheds will likely be an important step in reducing loads of PCBs to the Bay. However, a number of challenges lie ahead in the process of identifying and cleaning up important sources.

Identification of priority watersheds and location of specific source areas within them requires a careful combination of measurement and judgment. Previous approaches combining targeted sediment monitoring, land use analysis, and watershed and site inspection hold promise, but these methods are continuing to evolve.

Once source properties are identified, the challenge remains to obtain funding for remediation or identify responsible parties to perform abatement activities. Evaluation of abatement activities will also need to be conducted to determine what works and what does not. The lessons learned during the Ettie Street investigation will inform similar investigations and abatement in other Bay Area watersheds - an important part of the overall effort to reduce the amount of PCBs in the Bay and restore sport fishing and wildlife habitat beneficial uses. ●



# What is Causing the Phytoplankton Increase in San Francisco Bay?

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## Key Points

- Primary production by phytoplankton is the principal source of food for aquatic life in the Bay
- Prior to the late 1990s, phytoplankton biomass was persistently low except during events of rapid growth (blooms) in spring, usually between February and May
- Since the late 1990s, significant changes in phytoplankton population dynamics in San Pablo, Central, and South bays include larger spring blooms, blooms during other seasons, and a progressive increase in the “baseline” or annual minimum chlorophyll
- San Francisco Bay has been transformed from a low-productivity estuary to one having primary production typical of temperate-latitude estuaries
- Potential causes of the changes include a shift in currents in the Pacific Ocean, improved wastewater treatment, reduced sediment inputs, and introductions of new species

## The Bay's Food Factories

The largest living component of San Francisco Bay is the phytoplankton, a suspension of microscopic cells that convert sunlight energy into new living biomass through the same process of photosynthesis used by land plants. This **primary production** is the ultimate source of food for clams, zooplankton, crabs, sardines, halibut, sturgeon, diving ducks, pelicans, and harbor seals. From measurements made in 1980, we estimated that phytoplankton primary production in San Francisco Bay was about 200,000 tons of organic carbon per year (Jassby *et al.* 1993). This is equivalent to producing the biomass of 5500 adult humpback whales, or the calories to feed 1.8 million people. These numbers may seem large, but primary production in San Francisco Bay is low compared to many other nutrient-enriched estuaries.

Phytoplankton cells are microscopic in size but they are complete biochemical factories that synthesize a wide range of organic molecules, some of which are essential for animal life. We recognize the health benefits of eating fish because

← A red tide of the nontoxic organism *Mesodinium rubrum* near the Dumbarton Bridge on 7 May 2006. Photo courtesy of Scott Conard.

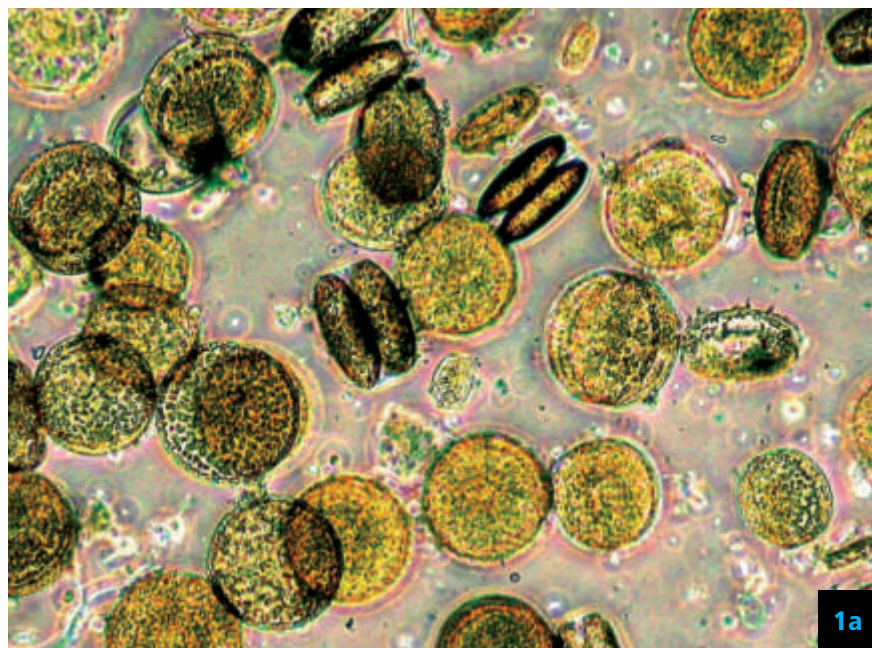
they are rich in omega-3 fatty acids, a dietary component that is synthesized by phytoplankton and passed through food chains to fish and their consumers. About 500 species of phytoplankton occur in the Bay (Cloern and Dufford 2005), and biomass is dominated by three groups: diatoms, dinoflagellates, and cryptophytes (Figure 1). Each species has its own unique repertoire of biochemical pathways. Some are harmful, producing toxins such as domoic acid which has killed fish, birds, and mammals in Monterey Bay.

Each year the Bay's phytoplankton produce calories equivalent to the amount needed to feed 1.8 million people

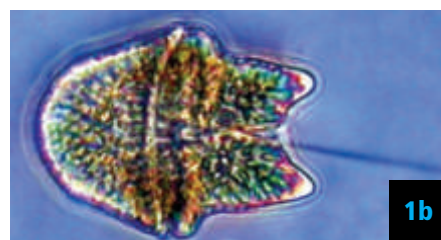
Phytoplankton cells absorb and concentrate dissolved substances, including toxic contaminants such as mercury, PCBs, and selenium. The mercury concentrations inside phytoplankton cells are about 10,000 times higher than in surrounding water (Kuwabara et al. 2005), so the biomagnification of mercury (and other pollutants such as selenium and PCBs) to toxic levels in fish and birds begins with phytoplankton absorption from water.

Nutrient enrichment from wastewater and fertilizer runoff has stimulated excessive phytoplankton production in many estuaries worldwide (Cloern 2001), leading to oxygen depletion as the decomposition of dead phytoplankton consumes oxygen from water faster than it can be replenished by mixing and aeration. Excessive phytoplankton production has created an expansive dead zone in the northern Gulf of Mexico and hypoxia with fish kills in Chesapeake Bay, the Baltic, Adriatic, and other coastal waters receiving large inputs of nitrogen and phosphorus.

Sustainability of food webs depends upon a continuing supply of phytoplankton biomass, but excessive supply can degrade habitat quality. Therefore, phytoplankton biomass is a critical component of estuarine health.



**1a.** Large marine diatom *Thalassiosira punctigera*: common in the coastal Pacific Ocean and forms large blooms in San Francisco Bay.



**1b.** Large marine dinoflagellate *Akashiwo sanguinea*: forms blooms in the coastal Pacific Ocean and formed a large red tide in San Francisco Bay during September 2004.



**1c.** **Cryptophytes:** small flagellates, present annually throughout San Francisco Bay, and a highly nutritious food resource for zooplankton and benthic invertebrates.

Photographs courtesy of Cary Lopez.

**Figure 1.** Phytoplankton biomass in San Francisco Bay is dominated by marine diatoms, dinoflagellates, and small flagellates, each species having distinct size, form, motility, life history, food value, and potential toxicity.

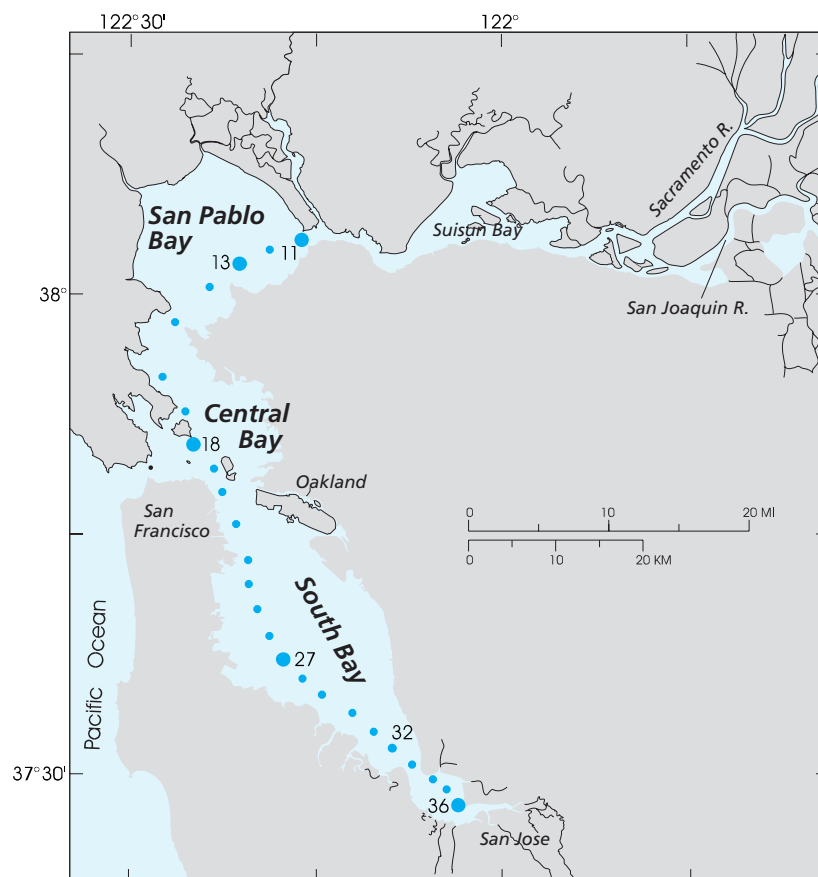


## Significant Changes in San Francisco Bay Phytoplankton

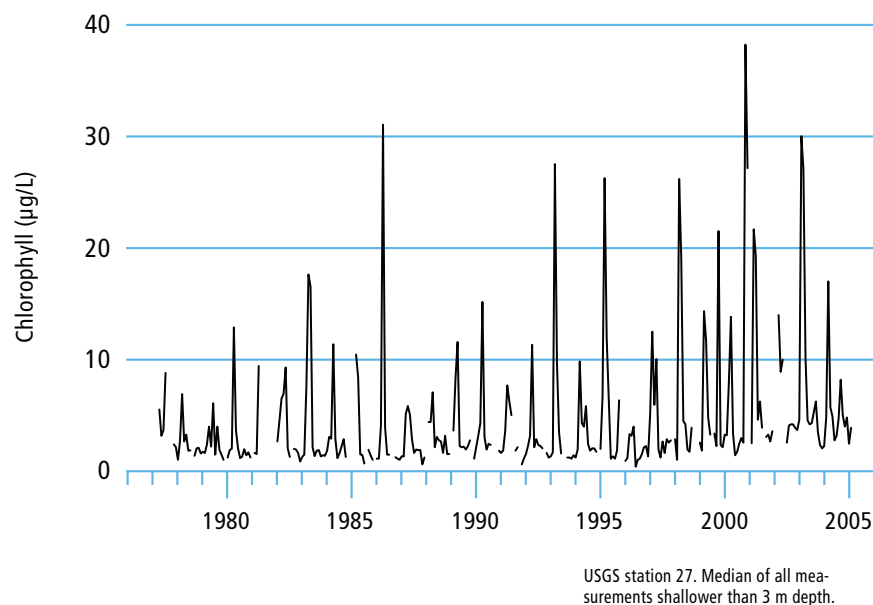
All phytoplankton cells contain chlorophyll as their primary light-harvesting pigment. We measure chlorophyll as an index of phytoplankton biomass at sampling stations (Figure 2) between lower South Bay and the Sacramento River. Figure 3 shows surface chlorophyll at USGS Station 27 (mid South Bay) between 1978 and 2005 (all data are available online: <http://sfbay.wr.usgs.gov/access/wq-data>). This series reveals a change that has occurred in the last decade or so. Prior to the late 1990s, phytoplankton biomass was persistently low except during events of rapid growth (blooms) in spring, usually between February and May. Since the late 1990s, we have observed blooms during other seasons and a progressive increase in the “baseline” or annual minimum chlorophyll. If we combine all surface measurements of chlorophyll made throughout San Pablo, Central, and South Bays, we see that spring blooms during some recent years have been larger than those seen prior to 1999 (Figures 4a versus 4b). These three patterns of chlorophyll change (larger spring blooms, new seasonal blooms, and higher baseline) represent systematic increases in all the marine domains (San Pablo Bay, Central Bay, and South Bay) of San Francisco Bay. This finding contrasts with trends of decreasing phytoplankton biomass in Suisun Bay (see Figure 2) where the Asian clam *Corbula amurensis* persists at high abundance (Alpine and Cloern 1992), and in the Sacramento-San Joaquin River Delta where primary production declined 43% during 1975-1995 (Jassby *et al.* 2002) and has remained low.



The USGS Research Vessel Polariss.  
Photo courtesy of Francis Parchaso.

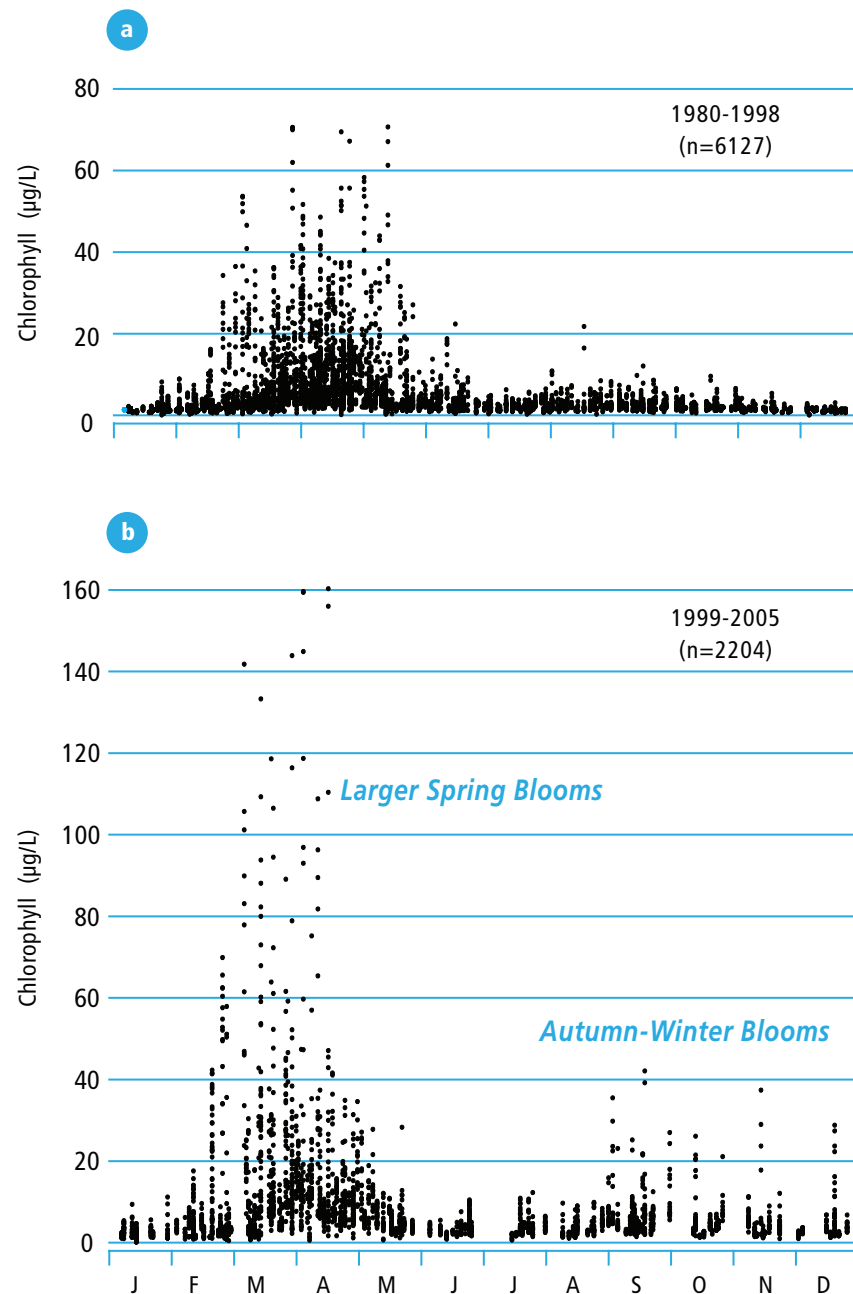


**Figure 2.** USGS measures water quality along a 150-km transect between the Sacramento River and lower South Bay as a component of the Regional Monitoring Program. Dots indicate locations of sampling stations between San Pablo Bay and South Bay, the marine domains of the Estuary where phytoplankton biomass has increased over the past decade.



**Figure 3.** ↑ **Phytoplankton biomass has increased in the marine domains of San Francisco Bay.** As an example, this series of monthly chlorophyll concentration shows an increasing baseline chlorophyll and occurrences of autumn-winter blooms in the past decade.

**Figure 4.** → **Changing phytoplankton dynamics in San Francisco Bay.** Top panel (a) shows daily measurements of surface chlorophyll in the marine domains (between stations 11-36) for years 1980-1998, a regime characterized by an annual spring bloom. Bottom panel (b) shows a regime shift after 1998 characterized by three changes: larger spring blooms, secondary blooms in autumn-winter, and increasing baseline chlorophyll (see Figure 3). Numbers in parentheses (n) indicate number of chlorophyll samples.





## A Closer Look at Trends in San Pablo, Central, and South Bays

We focus our analyses on changes that have occurred in the marine domains of San Francisco Bay since the RMP began in 1993. Trends of increasing chlorophyll were observed at all stations sampled. These trends were large, most in the range of 5-15% increase per year sustained over 12 years, and almost all were statistically significant.

The magnitude of spring blooms (maximum chlorophyll during February-May) increased at stations 11-27, between San Pablo Bay and the San Mateo Bridge (Figure 5a). The magnitude of fall blooms (maximum chlorophyll during July-December) increased at every station, and most of these trends were significant (Figure 5b). The spatial distribution and magnitude of these trends reflect the new occurrence of autumn-winter blooms in all the marine domains of the Estuary. Trend analyses also revealed significant system-wide increases of annual minimum chlorophyll (Figure 5c), confirming that the baseline phytoplankton biomass has increased year-round.

Chlorophyll monitoring within the RMP has revealed large systematic increases and changing seasonal occurrence of phytoplankton biomass in San Francisco Bay

Chlorophyll monitoring within the RMP has therefore revealed large systematic increases and changing seasonal occurrence of phytoplankton biomass in San Francisco Bay. These changes are ecologically important. From measures of daily solar radiation, chlorophyll, and turbidity we estimated the daily rate of primary production at each sampling time/location (Jassby *et al.* 2002), and then computed mean annual primary production along the transect from San Pablo Bay to lower South Bay. These computations indicate that primary production has increased 75%: estimated primary production between 1993-1996 was  $120 \text{ g C m}^{-2} \text{ y}^{-1}$  compared to  $215 \text{ g C m}^{-2} \text{ y}^{-1}$  for the years 2001-2004 (Figure 6). San Francisco Bay has been transformed from a low-productivity estuary to one having primary production within the range often measured in temperate-latitude estuaries. This enhanced primary production is a direct consequence of elevated phytoplankton biomass during bloom and nonbloom periods.

Figure 5

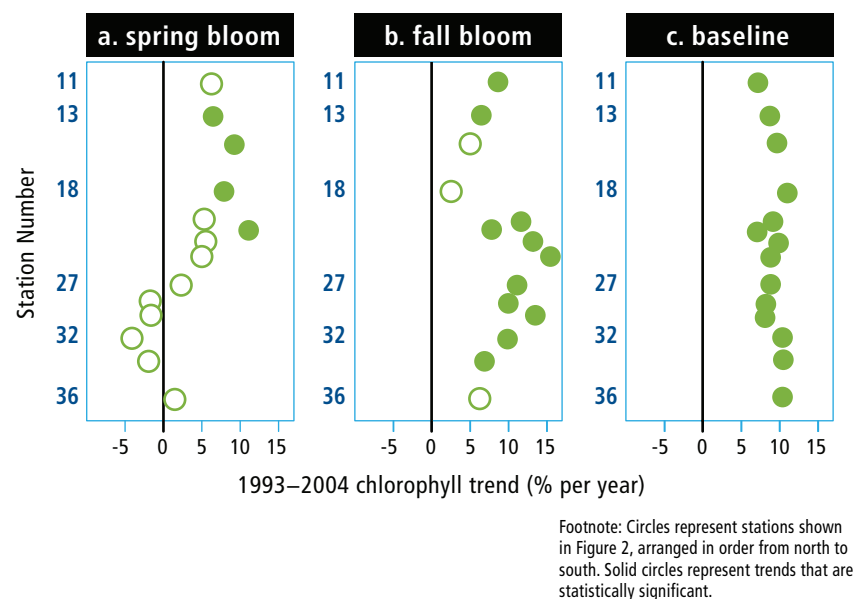
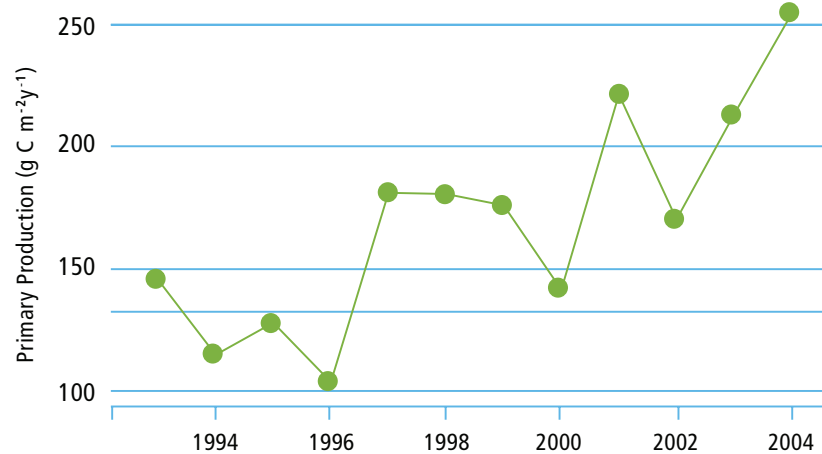


Figure 6



**Figure 5. Three trends of phytoplankton increase over the period 1993-2004.** The trends are measured as percent chlorophyll change per year, plotted against distance along the transect from the Golden Gate. The magnitude of the spring bloom (a) is indexed as the maximum chlorophyll concentration measured each year between February and May. Fall blooms (b) are indexed as the maximum chlorophyll concentration between July and December. Baseline phytoplankton biomass (c) is the annual minimum chlorophyll.

**Figure 6. Phytoplankton primary production has increased steadily since 1993.** Primary production was estimated from measurements of daily solar radiation, chlorophyll, and water transparency at stations between San Pablo Bay and lower South Bay.

## An Ecological Mystery—Why Has Phytoplankton Increased?

We know with certainty that phytoplankton biomass in San Francisco Bay has increased significantly over the past decade, but we may never discover the definitive cause or causes. We can, however, eliminate from consideration some potential explanations and highlight others that remain plausible. Dissolved inorganic nitrogen (DIN) and phosphate concentrations, two important forms of phytoplankton nutrients, are measured on some sampling cruises by USGS researchers. Trend analyses revealed insignificant changes in DIN, except at some stations in lower South Bay where decreases were significant (Figure 7a). Trends of phosphate concentration were negative at most stations, but these trends were not significant (Figure 7b). The weak trends of decreasing nitrogen and phosphorus concentration in the Bay are consistent with reduced nutrient input from wastewater treatment plants (Figures 8a,b). Therefore, the phytoplankton increase cannot be attributed to increases in nutrient concentration. To our knowledge, this is the first report of a large (75%) sustained increase in primary production in a coastal marine ecosystem that is not associated with elevated nutrient inputs.

Phytoplankton biomass is controlled by three general processes: (1) population growth that is regulated by resources (light, nutrients) and impaired by toxic pollutants (herbicides, heavy metals); (2) consumption by zooplankton and benthic suspension feeders such as bivalve mollusks (clams, mussels); and (3) transport processes such as tidal exchange with the coastal Pacific Ocean. Phytoplankton increases in San Francisco Bay could be caused by changes in any or all of these general processes. We list here five plausible mechanisms, each supported by field observations and presented as a hypothesis.

**Hypothesis 1: Regions of San Francisco Bay are becoming more transparent.** Trend analyses revealed a complex spatial pattern of decreased transparency between Central Bay and the northern regions of South Bay (stations 18-29), but increased transparency in San Pablo Bay and lower South Bay (Figure 7c). Phytoplankton growth rates are strongly limited in San Francisco Bay by low light availability caused by high suspended sediment concentrations. Trends of increased transparency in San Pablo Bay are consistent with sharp declines in the delivery of sediments from the Sacramento-San Joaquin Rivers between 1994 and 2002 (Figure 8e), and trends in South Bay are consistent with lower sediment input from the urban watershed associated with climatic varia-

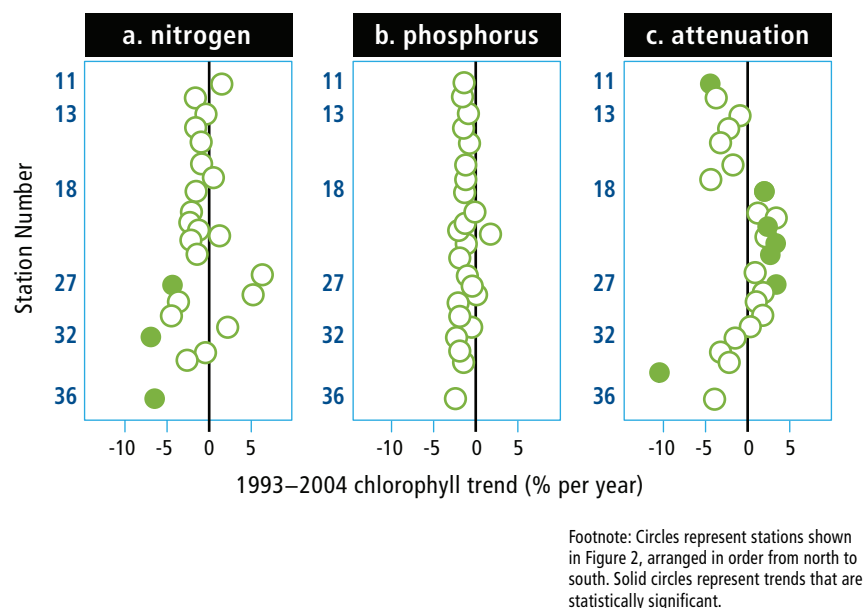
tion (Lester McKee, SFEI, personal communication). Is light limitation of phytoplankton growth slowly relaxing as sediment inputs and turbidity decrease?

**Hypothesis 2: Impairment by metal toxicity has decreased.** Phytoplankton photosynthesis and cell division can be impaired by heavy metals such as copper, a pollutant of concern in San Francisco Bay because it can strongly inhibit plant growth.

Continuing advancements in municipal wastewater treatment and industrial source controls have greatly reduced metal loading to San Francisco Bay. Annual loadings of cadmium and copper from the San Jose-Santa Clara Wastewater Treatment Plant decreased from 340 to 74 and 2600 to 480 kg y<sup>-1</sup>, respectively, from the 1980s to the 2000s (Figure 8c,d); some of these apparent trends reflect analytical changes and lower detection limits for elements such as cadmium. Similar trends have occurred for other metals (nickel, silver, chromium) and for other wastewater treatment plants. It may be impossible to test this hypothesis because assays of metal inhibition have not been made on phytoplankton communities over time. However, recent measurements show that copper in the South Bay has decreased to levels such that >99% of dissolved copper is bound by organic compounds into a form that is not biologically available and therefore nontoxic (Beck *et al.* 2002). Is phytoplankton biomass increasing because growth rates have increased in response to progress in wastewater treatment?

**Hypothesis 3: The ocean source of phytoplankton has increased.** We are slowly learning how variability in the coastal Pacific Ocean can induce changes inside San Francisco Bay, while oceanographers are learning how the Pacific Ocean is influenced by large scale atmosphere-ocean processes that oscillate over periods of decades. The 1992-2003 period was one of steadily increasing upwelling intensity following the 1975-1986 period of steadily declining upwelling (Figure 8f). Strong upwelling promotes growth of diatoms, and tidal mixing and currents can transport marine diatoms into San Francisco Bay. Some autumn-winter blooms in recent years (e.g., November-December 2000) were dominated by species such as *Thalassiosira punctigera* (Figure 1) that

One hypothesis is that phytoplankton biomass may be increasing because growth rates have increased in response to progress in wastewater treatment



**Figure 7.** ↑ Trends of dissolved inorganic nitrogen and phosphorus concentration and water transparency (attenuation coefficient) over the period 1993–2004. Trends are mean percent change per year and plotted against distance from San Pablo Bay (station 11) to lower South Bay (station 36). Solid circles represent trends that are statistically significant.

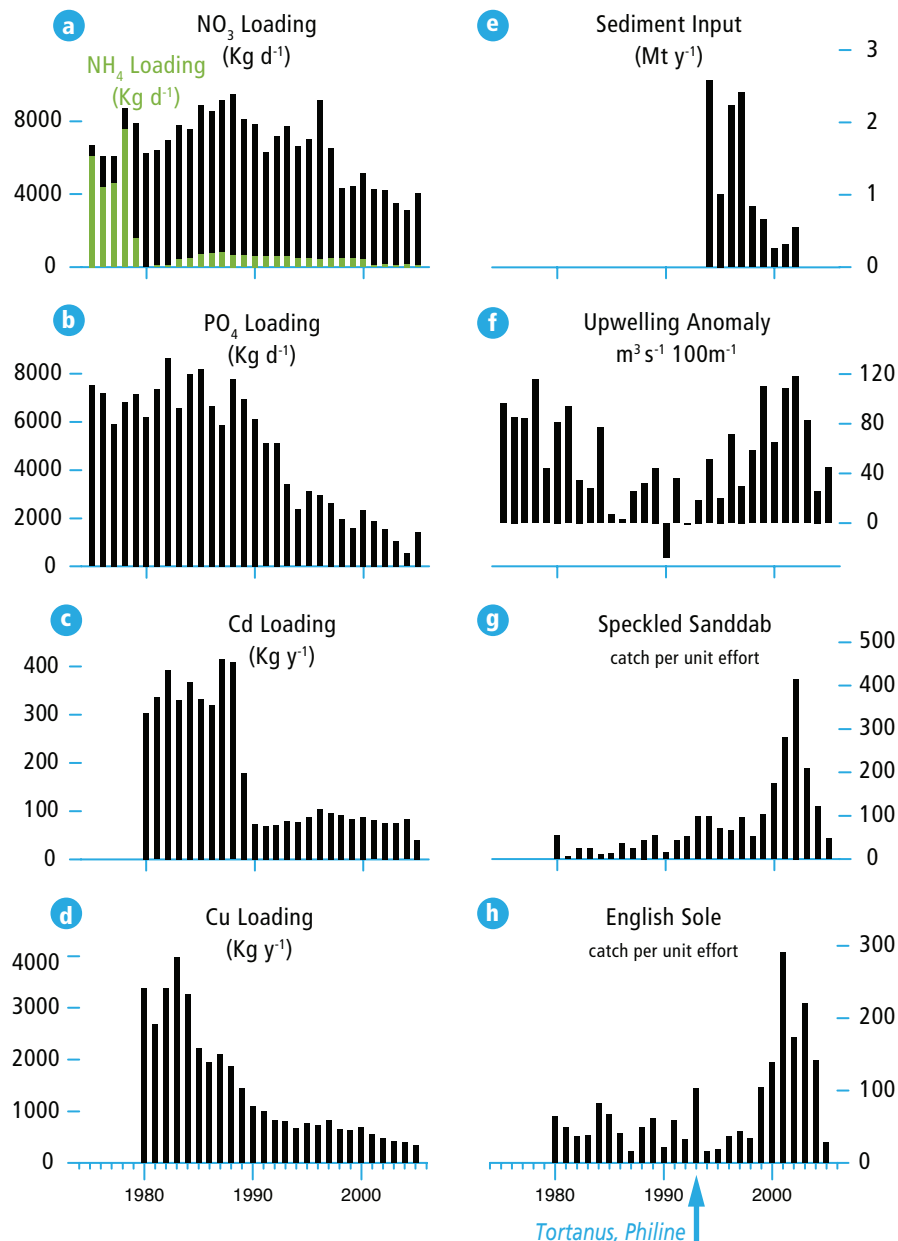
**Figure 8.** → Potential mechanisms of phytoplankton increase in San Francisco Bay. Loadings of nutrients (**a,b**: nitrogen, phosphorus) and toxic metals (**c,d**: cadmium and copper) from the San Jose-Santa Clara Wastewater treatment plant have declined since 1980. Sediment inputs from the Sacramento-San Joaquin Rivers (**e**) declined from 1994–2002, when primary production in the Bay nearly doubled. Upwelling intensity (**f**) has been higher than average since 1993. Recruitment and immigration of juvenile flatfish into San Francisco Bay (**g,h**) have been unusually high during the recent years of strong upwelling. The carnivorous copepod *Tortanus dextrilobatus* and the predatory gastropod *Philine auriformis* were first observed in 1993.

#### Acknowledgments

Figures 8a–d. Neal Van Keuren, Bob Wandro and Alo Kauravlla (Environmental Services Department, City of San Jose) provided annual wastewater loadings of nutrients and metals to South San Francisco Bay

Figures 8g and h. Kathy Hieb (California Department of Fish and Game) provided information on the distribution of *Philine* and access to fish catch data (Figures 8g,h) from the IEP Bay Studies Program.

Janet Thompson (U.S. Geological Survey) provided information on bivalve distributions from benthos sampling in April 2006.



Footnote:

River sediment input data from McKee et al. (2006)

Upwelling intensity (March–October deviation from the long term average Upwelling Index at  $39^\circ\text{N } 125^\circ\text{W}$ ) from NOAA Pacific Fisheries Environmental Laboratory: [www.pfeg.noaa.gov/products/PFEL/modeledindices/PFELindices.html](http://www.pfeg.noaa.gov/products/PFEL/modeledindices/PFELindices.html)

Flatfish data (mean Catch Per Unit Effort at sampling stations between San Pablo and South Bay) from California Department of Fish and Game: <http://ftp.delta.dfg.ca.gov/Bay%20Studies/>

are characteristic of upwelling events, so new seasonal blooms may have been triggered by offshore blooms during this recent era of anomalously strong upwelling. Relaxation of winds after strong upwelling promotes production of dinoflagellates, and in September 2004 we observed an unprecedented red tide inside San Francisco Bay that was dominated by *Akashiwo sanguinea* (Figure 1). This dinoflagellate formed red tides in Monterey Bay weeks earlier, providing strong evidence that phytoplankton blooms in San Francisco Bay can be seeded by cells produced offshore (Cloern *et al.* 2005). Do phytoplankton dynamics inside San Francisco Bay oscillate over multi-decade periods in association with fluctuations in the Pacific? Will chlorophyll concentrations in the Bay decline as upwelling returns to a normal regime?

**Hypothesis 4: Consumption of phytoplankton biomass by bivalves has declined because of high fish predation.** High offshore primary production enhances the energy supply to pelagic food webs that support fisheries production in the California Current. Recent years of strong upwelling have been years of high recruitment of fish that spawn offshore and use San Francisco Bay as a nursery for juveniles. Abundances of juvenile English sole and speckled sanddabs in San Francisco Bay increased in 1999-2000, attaining highest abundances since sampling began in 1980 (Figures 8g,h). These flatfishes feed on benthic invertebrates, including bivalve mollusks that play a critical role in filtering Bay waters and removing phytoplankton biomass. Is it possible that chlorophyll increases in San Francisco Bay are the result of a cascade through the food chain (or “trophic cascade”) in which high flatfish abundance, a consequence of climate-driven oceanic productivity, has reduced the abundance of bivalves and their consumption of phytoplankton? Such trophic cascades occurred following experimental introductions of predatory fish in lakes (Carpenter *et al.* 2001), but this hypothesis will be difficult to test because there is no continuing record of benthic invertebrate abundance across the marine domains of San Francisco Bay. Recent (April 2006) sampling revealed unusually low abundances of clams and mussels across intertidal and subtidal habitats of South Bay compared to similar sampling in the 1990s (Janet Thompson, U. S. Geological Survey, personal communication). However, the timing of this important biological change is unknown and the link to increased fish predation is speculative.



Photo courtesy of Francis Parchaso and Steve Hager

**San Francisco Bay is a different ecosystem now than when the RMP began in 1993**

**Hypothesis 5: Consumption by bivalves and zooplankton has declined because of new invasive predators.** San Francisco Bay continues to be invaded and transformed by alien species, and two ecologically-important invasions were discovered in 1993: the predatory copepod *Tortanus dextrilobatus* (Orsi and Ohtsuka 1999) and the carnivorous gastropod *Philine auriformis* (Gosliner 1995). The introduction of *Tortanus* may have increased phytoplankton biomass by reducing the abundance and population grazing rate of herbivorous copepods that eat phytoplankton (Hooft and Bollens 2004). The bottom-dwelling *Philine* feeds on small bivalves, and this predator may have altered the Bay ecosystem by reducing the abundance of suspension feeding bivalves that regulate phytoplankton biomass through their filtration of the water column. *Philine* is now widespread from San Pablo Bay

to South Bay, and its abundance has been high enough since 2001 to clog otter trawls and disrupt fish sampling in these portions of the Bay (Kathy Hieb, California Department of Fish and Game). Will the trends of phytoplankton increase continue if these predators persist and permanently disrupt the balance between phytoplankton production and consumption in San Francisco Bay?

## Implications for the Future Health of San Francisco Bay

Results presented here show that San Francisco Bay is a different ecosystem now than when the RMP began in 1993. We do not yet know the underlying causes of this transformation. Although analysis of the historical data enabled us to eliminate a number of potential causes, several possibilities still remain. Prominent among these are a regime shift in the Pacific Ocean, improved wastewater treatment, reduced sediment inputs, and introductions of new species. The large number of potential causes illustrates the daunting complexity of estuarine ecosystems and the challenge of interpreting biological monitoring data where changes are caused by multiple human and natural processes.

Our ability to solve the puzzle of phytoplankton increase is limited by two constraints. First, monitoring is usually designed to detect change in organism





Photo courtesy of Francis Parchaso and Steve Hager

abundance and water quality constituents but not to identify the underlying processes of change. The puzzle could be resolved with recurrent measurements of phytoplankton growth, grazing, and transport rates, but these kinds of processes are rarely measured in monitoring programs. Second, our ability to understand biological change is often limited by critical data gaps in variables such as organism abundance that are often

part of a monitoring program. Zooplankton and benthic invertebrate communities, for example, are not monitored in Central or South Bay, and phytoplankton biomass is not monitored in the adjacent coastal Pacific Ocean, so hypotheses of altered oceanic sources or enhanced within-Bay grazing sinks of phytoplankton biomass cannot be tested. We have done a good job supporting water quality and fish monitoring in San Francisco Bay, but not the intervening trophic levels, including plankton and benthos, and nutrients that limit biological production. These knowledge gaps are large constraints toward understanding mechanisms and ultimately in managing water quality and living resources.

Trends of increasing phytoplankton biomass in San Francisco Bay are notable because of the global problem of water-quality and habitat degradation caused by nutrient enrichment and stimulation of excess phytoplankton production. San Francisco Bay has been described as an estuary with inherent resistance to the harmful consequences of nutrient enrichment due to (1) strong light limitation of phytoplankton growth rate caused by high suspended sediment concentrations, and (2) fast consumption by clams and mussels (Cloern 2001). Results presented here suggest that this resistance might be changing as a consequence of multiple processes, including (1) reduced sediment inputs and a gradual clearing of Bay waters, and (2) (unexplained) population declines of bivalve mollusks. The many examples of estuarine eutrophication and harmful algal blooms elsewhere in the world remind us that continuing surveillance is essential to document the changing status of phytoplankton and the potential for water-quality problems associated with overproduction of algal biomass. Understanding and management of critical water quality change requires a comprehensive monitoring program that includes measurement of nutrient resources, transport processes such as Bay-Ocean exchanges, and abundances of invertebrates that consume phytoplankton cells. ●

Continuing surveillance is essential to document the changing status of phytoplankton and the potential for water-quality problems associated with over-production of algal biomass



## Pyrethroid Insecticides in the Estuary—Solution or New Threat?

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1 UC Berkeley 2 San Francisco Estuary Institute 3 Independent Consultant (werme@sbcglobal.net)



### Key Points

- With the withdrawal of organophosphate insecticides from most urban uses, pesticide manufacturers have turned to the pyrethroids
- Agricultural uses exceed non-agricultural uses in the Central Valley during the summer, but statewide, non-agricultural uses, such as professional termite control and landscape maintenance are greater; pyrethroids are also widely available to retail customers for home and garden use
- Pyrethroids are very toxic to fish and aquatic invertebrates
- Pyrethroids have been found in most sediment samples tested in California, in both agricultural and urban watersheds, and can often be linked to toxicity to sensitive aquatic species



### First, the Good News

Over the past five to ten years, water quality in the San Francisco Estuary and its watersheds has been less impacted by insecticides. Through the 1990s, it was common to find long reaches of the Sacramento and San Joaquin rivers and their tributaries that were toxic to *Ceriodaphnia dubia*, the small water flea that is routinely used for toxicity testing of water. If the pollutants responsible for the toxicity could be identified, the culprits consistently were either of two organophosphate insecticides, diazinon or chlorpyrifos.

Agricultural use of organophosphate insecticides has been reduced to about half the levels of the mid-1990s, and urban use has been almost entirely eliminated. It is now rare to find acute toxicity in the major rivers, and water quality in urban creeks has improved. Toxicity is sometimes measured in smaller agricultural tributaries close to the points of pesticide application, but less frequently.



## Derived From an Ancient Solution

With the reduction of organophosphate insecticide use, pesticide manufacturers have turned to a class of insecticides similar to one that has been around for centuries. Daisy-like pyrethrum flowers (certain species of chrysanthemum) have been known for their ability to kill insects for thousands of years, and dried flowers were traded along the Silk Route from Western Europe to Asia. By World War II, the flowers were extensively cultivated in Africa, and more recently in Tasmania. The natural forms of the pesticide are known as pyrethrins. Synthetic forms are called pyrethroids; they are typically more toxic to insects and more environmentally persistent than the natural forms.

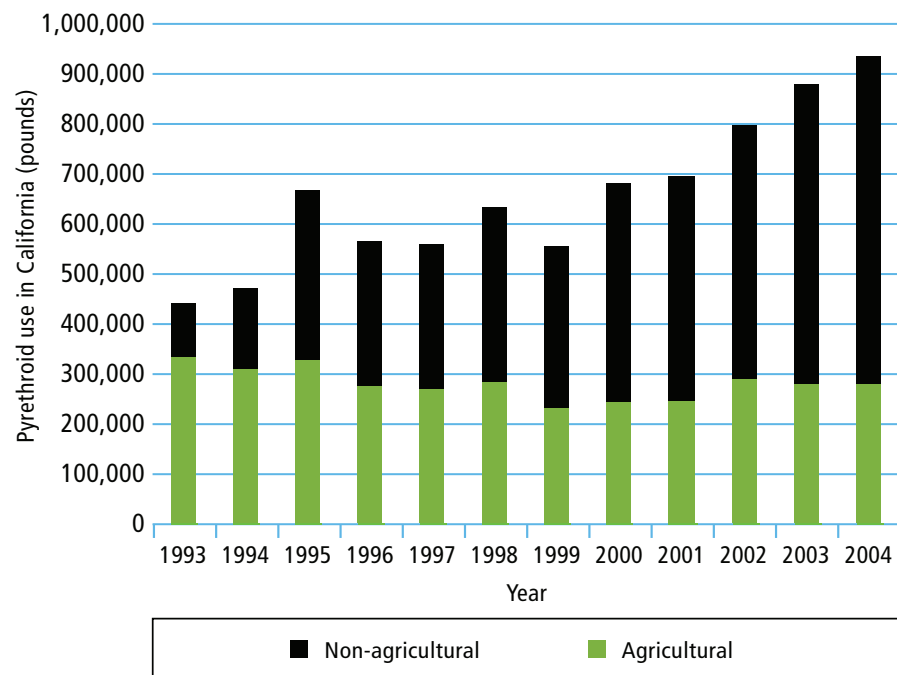
Today pyrethroids are used on agricultural row crops, including alfalfa, cotton, lettuce, and tomatoes, and in orchards, on almonds, pistachios, peaches, and walnuts. Non-agricultural uses (most of which would be characterized as “urban”) include professional ant and termite control and professional lawn and garden care. Pyrethroids are also readily available to retail customers in products geared towards lawn and garden care, home pest control, and pet sprays and shampoos. They can often be recognized by the “thrin” suffix in the list of active ingredients on product labels (e.g., permethrin, bifenthrin, cyfluthrin, lambda-cyhalothrin, and cypermethrin; esfenvalerate is an exception to this general rule).

For some California crops, there have been significant increases in pyrethroid use. Applications of pyrethroids to almonds and stone fruit more than doubled during the 1990s. However, total agricultural applications of pyrethroids have been fairly stable in recent years ([Figure 1](#)). The California Department of Pesticide Regulation reports that slightly less than 282,000 pounds of pyrethroids were applied to all agricultural crops in the state in 2004, about one-eighth the amount of diazinon and chlorpyrifos reported. Even on almonds and stone fruits in the Central Valley, the amounts of pyrethroids used are much smaller than the amounts of organophosphates ([Figure 2](#)).

In the summer months in the Central Valley, agricultural uses dominate over non-agricultural uses ([Figure 3](#)). But in many months of the year and throughout the state as a whole, non-agricultural uses dominate and have seen greater increases. Professional, non-agricultural applications totaled about 665,000 pounds in 2004, over twice what was used in agriculture and an 11% increase from the previous year. Non-agricultural use of pyrethroids by professional applicators is currently about six times the amount used in the early 1990s. Retail sales are not included in these figures, but have also increased.

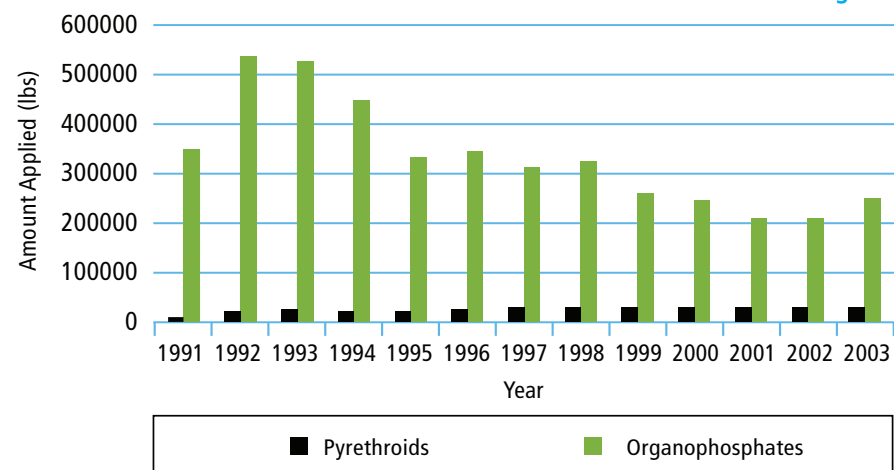
*Central Valley almond orchard in bloom. Photo courtesy of Jay Davis.*



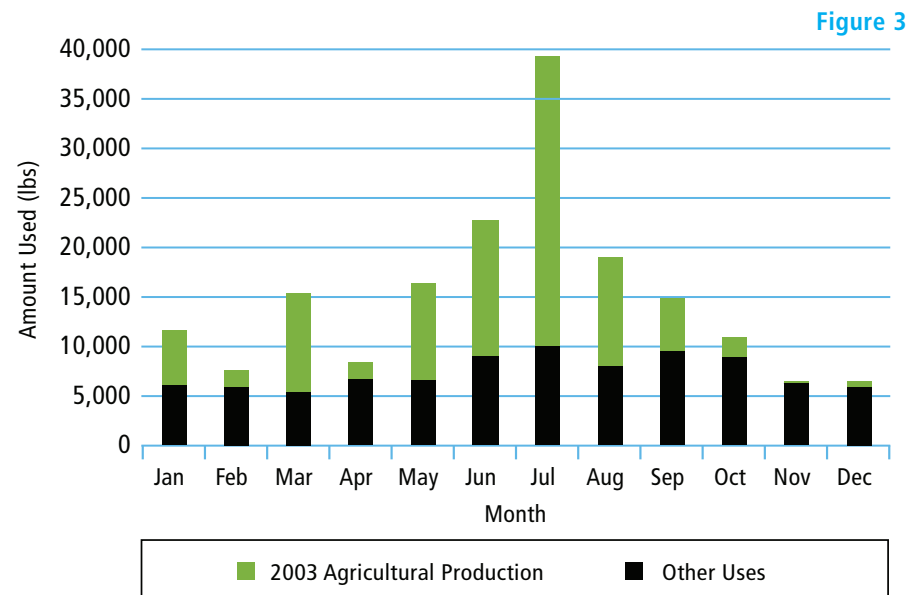


Data are from the Pesticide Use Reporting database of the California Department of Pesticide Regulation and do not include retail sales.

**Figure 1.** Statewide use of pyrethroids by professional applicators has increased over the past decade, particularly for non-agricultural uses, such as structural pest control and professional landscaping.



**Figure 2**



**Figure 3**

Data are from the Pesticide Use Reporting database and do not include retail sales.

**Figure 2.** Applications of organophosphate insecticides to almonds and stone fruits in the Central Valley have declined, while applications of pyrethroids have increased. However, the total amount of pyrethroids used remains small in comparison to the amount of organophosphates.

**Figure 3.** In the summer months in the Central Valley, agricultural uses exceed non-agricultural applications, while non-agricultural applications dominate in the remainder of the year.

## Pyrethroids in the Sewage Stream

As innovative companies have responded to health issues such as West Nile virus, Lyme disease, head lice, and asthma, they have developed new uses for pyrethroids. Some of these new uses have municipal treatment plant operators worried.

One example is BUZZ OFF™ Insect Shield Repellent Apparel, marketed as “the first insect-repellent clothing to be registered by the U.S. Environmental Protection Agency.”

The Centers for Disease Control and Prevention (CDC) recommend applying repellents (such as DEET) to skin and spraying pyrethroids on clothing to guard against mosquito- and tick-borne diseases. Impregnated with permethrin, BUZZ OFF™ shirts, pants, hats, and socks are marketed as convenient alternatives to repellents and pyrethroid sprays.

Likewise, permethrin-containing mattresses, bedding, upholstered furniture, and rugs are being sold to control household dust mites, which have been implicated in dramatic increases in asthma suffering. Pyrethroids are also found in head-lice shampoos, over-the-counter and prescription drugs, pet shampoos, carpet treatments, and ant sprays.

Marketing information for BUZZ OFF™ indicates that it holds up through 25 washings—but its EPA registration instructs users to wash the treated items separately. That’s because permethrin comes off in the wash in tiny fiber fragments, and it could contaminate other clothing. The permethrin-impregnated fragments also go down the drain and to the sewer system. Municipal treatment plants may sometimes receive concentrated pulses of pyrethroids, if for example, a school treats an outbreak of head lice with insecticidal shampoo.

There have been very few measurements of pyrethroids in the influent or effluent of Bay Area municipal treatment plants, and there have been no studies of removal efficiencies. So the extent to which pyrethroids enter the Estuary and watersheds through effluent discharges or re-use of municipal sludges as fertilizers is not known.

Tri-TAC, a technical advisory committee representing the League of California Cities, California Association of Sanitation Agencies, and California Water Environment Association, has expressed concerns about pyrethroids and other new “down-the-drain” pollutants. Tri-TAC has encouraged the California Department of Pesticide Regulation and the EPA to consider the effects on municipal discharges as they re-evaluate or re-register the pyrethroids.

## And the Bad News?

Pyrethroids are less toxic to birds than the organophosphates, and less acutely toxic to humans and other mammals, though they may pose a cancer risk. However, they can be extremely toxic to aquatic invertebrates and fish. In fact, pyrethroids are several times more toxic to fish than the organophosphate insecticides that they are replacing. Aquatic invertebrates, such as amphipods and copepods, are even more sensitive than fish. The LC50s (the concentra-

Pyrethroids can  
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tions that are lethal to 50% of a group of test organisms) for pyrethroids are about one part per billion for many fish, and one-tenth of that for many aquatic invertebrates. Concentrations that cause sublethal effects are even lower. The effect of increased use of pyrethroids on fish and their food organisms is one factor that has been suggested as a contributor to the recent declines of fish populations in the Sacramento-San Joaquin River Delta (Oros and Werner 2005), though the link remains unproven.

Recent studies have shown that both agricultural and urban uses of pyrethroids can potentially contaminate surface waters and sediments. Unlike organophosphate insecticides, sediment contamination is the major concern; pyrethroids bind to the sediments about 50 times more strongly than do the organophosphates.

## Toxic Effects from Agricultural Sources

In a broad survey of Central Valley sediments, seven out of ten sediment samples contained measurable levels of pyrethroids (Weston *et al.* 2004), while pyrethroids were found in less than one out of ten water samples (CVRWQCB 2005a, 2005b). Toxicity was also greater in those sediment samples. About 28% of the sediment samples from areas affected by agricultural runoff were toxic to an organism commonly used in freshwater sediment toxicity tests, the amphipod *Hyalomma azteca*. Comparing the concentrations of pyrethroids in the samples with levels known to be toxic, it appeared that pyrethroids were responsible for measured toxicity in about 70% of the cases. In contrast, the State’s Irrigated Lands Program has found that only about 5% of Central Valley water samples were toxic to *Ceriodaphnia dubia*, the common species for water toxicity testing. Toxicity could usually be attributed to an organophosphate insecticide. Overall, sediments from Central Valley waterways are about five times more likely to be toxic than water samples, and if toxicity is observed, it is more likely to be due to pyrethroids.



## How Application of Lawn Insecticides Might Contaminate an Urban Creek

Assume you want to apply insecticide to your lawn, perhaps even fertilizing it at the same time. Many lawn insecticides contain bifenthrin, the pyrethroid that appears to contribute most to the toxicity seen in the sediments of urban creeks. There are many products available, but as an example, assume you select Scott's Turf Builder® with Summerguard. (Summerguard is Scott's trade name for bifenthrin.) You have a modest size suburban lawn of 20 by 20 feet, and you apply at the recommended rate, using a little over a pound of product, less than a tenth of the bag. You make only one application, heeding label directions to wait two months before reapplying. The single application results in dispersal of 410 mg of bifenthrin over your lawn.

Some unknown amount of bifenthrin is likely to leave the lawn with irrigation runoff, or the runoff may carry granules that you left behind on the driveway or sidewalk if you failed to sweep these surfaces clean. Hypothetically, assume that 1% of the amount applied (4.1 mg bifenthrin), gets washed off your property, goes down the storm drain at the curb, and is discharged to the nearest creek where it becomes incorporated in to the creek sediments.

How much will nature have to dilute that 1% of "lost" bifenthrin in order for those sediments to support *Hyalella azteca*, the crustacean widely used for testing sediment toxicity? In order to answer that question we have to know the bifenthrin concentration at which *Hyalella* toxicity appears (about 0.25 µg bifenthrin per gram sediment organic carbon), we have to assume how much water is in that wet mud in the bottom of the creek (about 40% of the weight is water) and we have to assume a typical amount of organic carbon in the sediment (say, 2%). But with these estimates, that 1% of bifenthrin lost from that one application to your lawn is enough to contaminate about one and a half tons of wet mud in the creek to a level toxic to *Hyalella*!

One and a half tons is a big number, but perhaps to better illustrate the toxicity of these compounds, and the sensitivity of aquatic life, think of it another way. You would have to dump 90 tons of dirt on your hypothetical 20 by 20 ft front yard (don't forget to rototill it in thoroughly) in order to reduce the concentration of the bifenthrin you just applied below its lethal level for *Hyalella*.

The extent to which lawn applications contribute to the bifenthrin found in urban creeks is unknown. Lawn insecticides sold to homeowners make up only 7% of the non-agricultural bifenthrin used in California. How much of the lawn products are left on impermeable surfaces such as driveways or the fraction that leaves a lawn during irrigation is unknown. Application of bifenthrin outdoors around structures by professional pest exterminators to control ants and other insects may be an equal or even much greater source.



## Pyrethroids Commonly Found in Retail Products

- Permethrin
- Bifenthrin
- Cyfluthrin
- Lambda-cyhalothrin
- Cypermethrin
- Deltamethrin
- Resmethrin
- Esfenvalerate

These names can be found in the listing of "Active Ingredient" on product labels. Avoiding use of these chemicals can help reduce the impacts of pesticides in our creeks, streams, and the Bay. Non-chemical alternatives for pest control are preferable to chemical pesticides and include physical barriers, soaps and oils, biological controls (introduction of pest predators or pest-targeting microbes), and cultural controls (good housekeeping and gardening practices). More information on pesticide alternatives is available at the "Our Water Our World" website: [www.ourwaterourworld.org](http://www.ourwaterourworld.org)



Whether pyrethroids from the agricultural Central Valley reach the San Francisco Estuary has not been established. In assessing the potential for effects on Delta fish, Oros and Werner (2005) calculated that the potential transport of only 0.1% of the pyrethroids applied in the Central Valley could hypothetically result in sediment toxicity in Suisun Bay. Because pyrethroids are almost exclusively associated with sediment particles, long-range transport would depend on high flows. Conceivably, irrigation return flows (water diverted for irrigation and then returned to the waterway) may be a mechanism for transporting pyrethroids from fields to nearby creeks and agricultural drains during the growing season. High winter flows that move sediments may be more important in transporting pyrethroids from small tributaries near farms to the larger rivers that flow to the Delta.

Available data suggest a gradient of pyrethroid-related toxicity from the small tributaries to the rivers (Weston, unpublished data). Toxicity was measured in 44% of 32 sampling sites in small agricultural drains, but only 27% of eleven sites in rivers. Toxicity was found in only one sample of twelve from the San Joaquin River and no sediment toxicity was seen in a single sample from the Sacramento River.

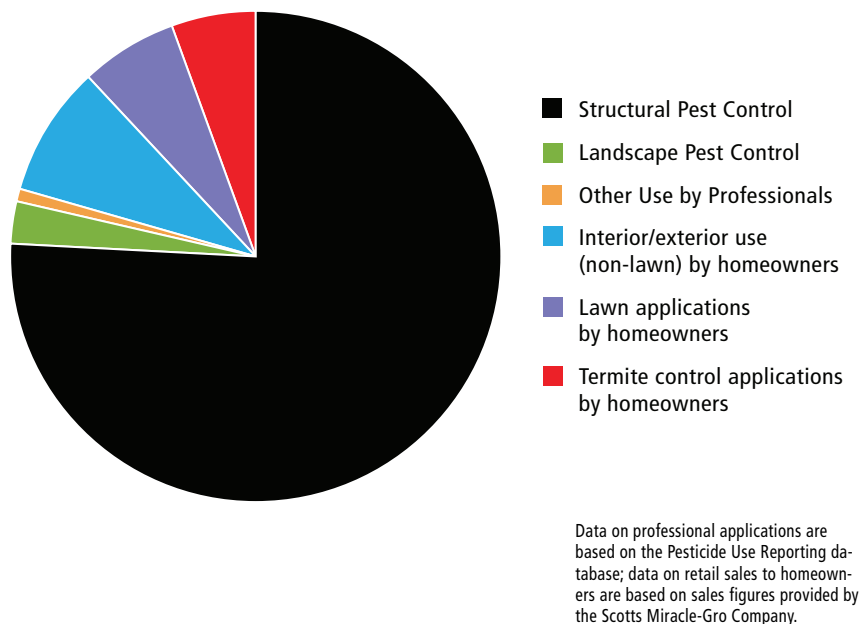
## Toxic Effects from Urban Sources

Urban uses of pyrethroids are about twice those of agriculture, and by their very nature, urban applications are made in relatively concentrated geographic areas. Thus, the potential for pyrethroids to occur in urban creek sediments exists, but the first data demonstrating their presence has only recently been published. In a study of urban creeks draining the residential subdivisions of Roseville, a suburb of Sacramento, almost every sediment sample showed toxicity, and about half the samples caused near total mortality to the test animal *Hyalella azteca* (Weston *et al.* 2005). In each instance, the concentrations of pyrethroids were high enough to have caused the toxicity. Concentrations of pyrethroids in sediments near storm-drain outfalls were 40 times higher than concentrations known to be toxic to the test animals.

A subsequent study found that sediments from six of seven Sacramento creeks were toxic, with high enough levels of pyrethroids to account for the toxicity (Amweg *et al.* 2006). Sediments from five of seven East Bay creeks were also toxic, although pyrethroids could only definitely be implicated in one creek and possibly in two others.

The practices and processes that lead to pyrethroids in urban creeks have not been firmly established, but identification of specific pyrethroids provides some clues. Bifenthrin was the product of greatest concern, contributing about 70% of the pyrethroid-related toxicity in Roseville, 58% in Sacramento, and 37% in the East Bay. Of the bifenthrin sold in California in 2003 for non-agricultural purposes, 76% was used for structural pest control by professionals, with 21% sold to homeowners (Figure 4). Which of these two user groups represents the greater source is unclear, in part because both categories include some use below ground for termite control, with presumably less potential for run off into local creeks.

Two other pyrethroids found in urban creeks, cypermethrin and deltamethrin, are almost certainly attributable to structural pest control by professional applicators, as their availability in retail products is limited. Two pyrethroids linked to urban creek toxicity, lambda-cyhalothrin and cyfluthrin, are used by both professional applicators and homeowners.



**Figure 4.** Of the 56,208 pounds of bifenthrin used in California in 2003 for non-agricultural purposes, most was used for structural pest control. Retail sales to homeowners represented about one-fifth of the total.

## The Challenge Ahead

Within the watersheds of the Sacramento and San Joaquin rivers there has been an historical emphasis on water column monitoring, probably driven by the need to assess toxicity of the more water soluble organophosphate insecticides. In San Francisco Bay sediment monitoring has been more common, but it has focused on the now-banned chlorinated compounds (such as PCBs, DDT, and chlordane) or on toxic metals, such as mercury and copper. Now we are finding that we have not given enough attention to other pollutants. Pyrethroids have been on the market for decades, and their use in the 1980s and 1990s, at least in agriculture, was comparable to amounts used today. Yet despite this long history of use, there have been few studies of pyrethroids in aquatic sediments, not only regionally, but on a national basis.

There are challenges in studying pyrethroids. Because they are toxic at such low levels, they must be detectable at extremely low levels. And because there are many different pyrethroid compounds, laboratories must continually ensure that they are analyzing for the constantly changing suite of compounds in use. The variety of pyrethroid compounds also complicates toxicological studies. For some pyrethroids, there are no established toxicity thresholds for sediment dwelling animals, and the possible cumulative effect of multiple pyrethroids is not well documented.

Because pyrethroids are largely associated with the sediments rather than the water column, monitoring and assessment should include an emphasis on the sediments. In agricultural areas of the San Francisco Bay watershed, sediment monitoring for pyrethroids is becoming more common. In urban environments, sediment monitoring for the compounds is not yet well established, perhaps because evidence for their presence has only recently emerged. In light of the concentrations of pyrethroids now known to occur in urban creeks and the frequency of toxicity, there is adequate justification for initiating such efforts.

There is still some good news. The fact that pyrethroids bind so readily with sediments may aid in mitigating impacts. Particle-trapping structures, such as vegetated drainage ditches on agricultural lands, may be effective in reducing transport of pyrethroids to waterways. Meanwhile, there is much to learn about pyrethroids, their potential effects, and means of mitigation. The work is underway, much of it here in California. ●

There is much to learn about pyrethroids, their potential effects, and means of mitigation









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## A Primer on Bay Contamination

### Question

**How contaminated is the Estuary?**

### Answer

Water and sediment of the Estuary meet cleanliness guidelines for most pollutants. However, a few problem pollutants are widespread in the Estuary, making it rare to find water or sediment in the Estuary that is completely clean. A fish consumption advisory remains in effect due to concentrations of mercury (page 31), PCBs (page 30), dioxins, and organochlorine pesticides of potential human health concern in Bay sport fish. A duck consumption advisory is also in effect due to selenium concentrations of potential human health concern (page 31). Toxicity testing over the past 13 years has found that more than half of sediment samples tested were toxic to at least one species of test organism (page 33). The 303(d) List (page 12) is the official list of pollutants of concern in the Estuary.

### Question

**Is the contamination getting better or worse?**

### Answer

Over the long term, the Estuary has shown significant improvements in basic water quality conditions, such as the oxygen content of water, due to investments in wastewater treatment. Contamination due to toxic chemicals has also generally declined since the 1950s and 1960s. More recently, however, the answer to this question varies from pollutant to pollutant. Mercury concentrations in striped bass, a key mercury indicator species for the Estuary, have shown little change in 30 years. PCB concentrations appear to be gradually declining based on trends observed in mussels (page 32), fish (page 30), and birds. Concentrations of DDT, chlordane, and other legacy pesticides have declined more rapidly. On the other hand, concentrations of chemicals in current use, such as pyrethroid insecticides (page 71) and polybrominated diphenyl ethers (PBDEs) (page 22) are on the increase. Aquatic toxicity has declined in the past few years, possibly associated with reduced usage of organophosphate pesticides. Sediment toxicity, on the other hand, has consistently been observed in a large proportion of samples tested over the past ten years (page 33).





### Question

## Are pollutants harming populations of organisms in the Estuary?

### Answer

This critical question remains largely unanswered. There are indications that the current level of contamination is harming the health of the ecosystem, such as the frequent occurrence of pollutants above water, sediment, and fish tissue guidelines, and the toxicity of water and sediment samples to lab organisms. Mercury concentrations appear to be high enough to cause embryo mortality in clapper rails, an endangered species found in Bay tidal marshes, and to impact development of young Forster's terns. PCB concentrations may be high enough to also cause low rates of embryo mortality in Bay birds and to affect immune response in harbor seals. Selenium concentrations appear to be high enough to cause abnormalities in early life stages of Sacramento splittail and white sturgeon. Pollutant mixtures appear to similarly affect early life stages of striped bass. Assessments of benthic communities in the marine and estuarine regions of the Bay indicate that some areas are impacted by pollutants.

### Question

## Do we know how to clean up the Estuary?

### Answer

**There are three general approaches to Estuary clean-up.**

#### **1. Reducing the entry of additional pollutants is essential.**

The Estuary acts as a long-term trap for persistent pollutants; once pollutants enter the Estuary it takes a very long time for them to exit. Preventing pollutants from entering the Estuary is therefore imperative. Preventing a pollutant from entering the Estuary requires knowledge of the source or a point where the transport can be intercepted. Detailed descriptions of the sources, pathways, and repositories of contamination for several pollutants of concern are under development. Much of this effort is in response to the Clean Water Act's requirement to develop pollutant clean-up plans known as Total Maximum Daily Loads. While known pollutant problems are being addressed by TMDLs, surveillance monitoring is conducted in the RMP in an effort to provide an early warning for pollutants of emerging concern and allow for management actions to nip potential problems in the bud.

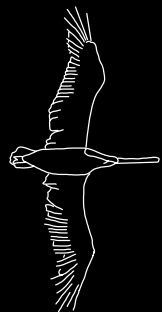
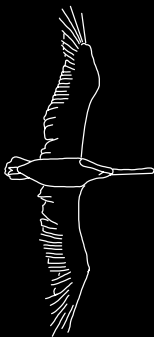
#### **2. Removing some masses of pollutants from the Estuary is possible.**

Contaminated sediment can be dredged from the Estuary, placed on land and sealed with a layer of asphalt or similar material. Such dredging has been attempted in a few cases with mixed results.

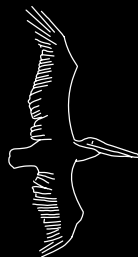
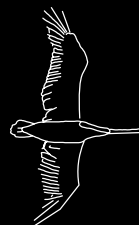
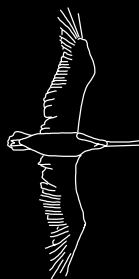
#### **3. Allowing pollutants to degrade and disperse naturally is necessary.**

Time is a large part of the remedy, naturally reducing the large quantity of pollutants now in the sediments through degradation, and transport to the ocean and atmosphere. Burial in deep sediment is normally a removal process in estuaries, but due to a reduced supply of sediment to the Estuary, burial is not occurring. For persistent pollutants found in large amounts in the sediments of the Estuary, such as mercury and PCBs, the time required to see change will be decades.





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