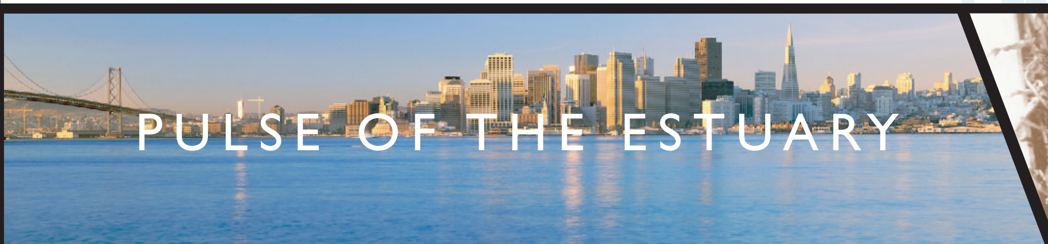
2003



PULSE OF THE ESTUARY

monitoring & managing contamination in the san francisco estuary

SFEI

RMP 10 Year Anniversary 1993 2003

About This Report

This year marks the tenth anniversary of the San Francisco Estuary Regional Monitoring Program for Trace Substances (RMP). This milestone represents an appropriate time to examine how scientific understanding, regulation, and the degree of contamination in the San Francisco Estuary have changed over the course of a decade. The synthesis of findings from this first phase of the RMP is providing a general theme for the Program in 2003 and 2004. An integrated series of products and events are planned to accomplish an evaluation and long-term summary of the many components of the Program, including:

Short on time? Just look at the figures and captions. They provide key findings in a nutshell.

- the 2003 and 2004 issues of the *Pulse of the Estuary*,
- the 2003 and 2004 RMP Annual Meetings,
- a report summarizing the Program's successes and challenges for the future from a management perspective, and
- a Status and Trends Report that will summarize what has been learned from the RMP and other studies about contamination in the Estuary over the past 10 years.

This issue of the *Pulse* is the first of two consecutive issues dedicated to analysis of the initial 10 years of the RMP. In addition to the usual features of the *Pulse* summarizing the latest data on contamination in the Estuary, this issue contains feature articles focusing on specific components of the multifaceted Program. A particular highlight this year is an article by Jim Cloern and colleagues at USGS that provides an interesting overview of basic ecological lessons learned from 10 years of monitoring water quality in the Bay.

This issue of the *Pulse* has been designed to make information on water quality in the Estuary more accessible. More detailed figure captions have been written that convey the basic take-home messages of each article. Readers that are pressed for time can glean many of the important findings from the *Pulse* by simply reviewing the figures and captions. The Status and Trends Update is now presented entirely as a graphical summary.

The *Pulse of the Estuary* is one of three RMP reporting products. The second product, the *Annual Monitoring Summary*, is distributed via the SFEI web site <www.sfei.org> and includes narrative summaries and comprehensive data tables and charts of the most recent monitoring results. The third product is the *RMP Technical Reports* collection. *RMP Technical Reports* each address a particular RMP study or topic relating to contamination of the Estuary. A list of all RMP technical reports is available at <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.

This report should be cited as: San Francisco Estuary Institute (SFEI). 2003. The Pulse of the Estuary: Monitoring and Managing Contamination in the San Francisco Estuary. SFEI Contribution 74. San Francisco Estuary Institute, Oakland, CA.

2000

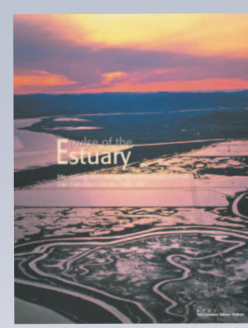
Premier issue:
- *Introduction to RMP Monitoring*

Feature articles:
- *Top Known Contamination Problems*
- *Contamination of Water, Sediment, and Fish*
- *Summary of Overall Condition*

2001

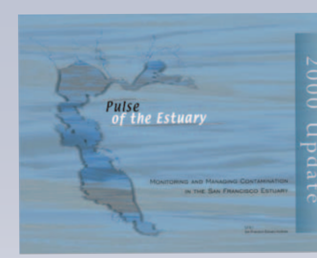
Introduced Pulse feature:
- *San Francisco Estuary Contamination Overview*

Feature articles:
- *Using the RMP to Help Manage the Estuary*
- *Unidentified Contaminants: Hidden Threat?*
- *Tracking Down Contaminant Sources*
- *Analyzing Contaminant Movement and Storage*
- *Improving Contaminant Effects Monitoring*
- *Fitting the RMP into the Monitoring Milieu*



2002

Feature articles:
- *The Five Decade Forecast for PCBs in the Bay*
- *Measuring the Adverse Effects of Contaminants: A New Emphasis*
- *Closing in on Unidentified Contaminants*
- *A New Approach to Sampling Water and Sediment*



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What is the RMP?

An innovative partnership

The RMP has combined shared financial support, direction, and participation by regulatory agencies and the regulated community in a model of collective responsibility. The RMP has established a climate of cooperation and a commitment to participation among a wide range of regulators, dischargers, industry representatives, community activists, and scientists. The RMP provides an open forum for interested parties to communicate about contaminant issues facing the Bay.

An adaptive, long-term program of study in support of management

Stable funding has allowed the RMP to develop an efficient structure that enables the Program to adapt to changing management priorities and advances in scientific understanding. RMP committees and workgroups meet regularly to keep the Program focused on the highest priority issues, efficient, and based on sound science. The RMP has continually improved since its inception in 1993.

A high quality body of knowledge

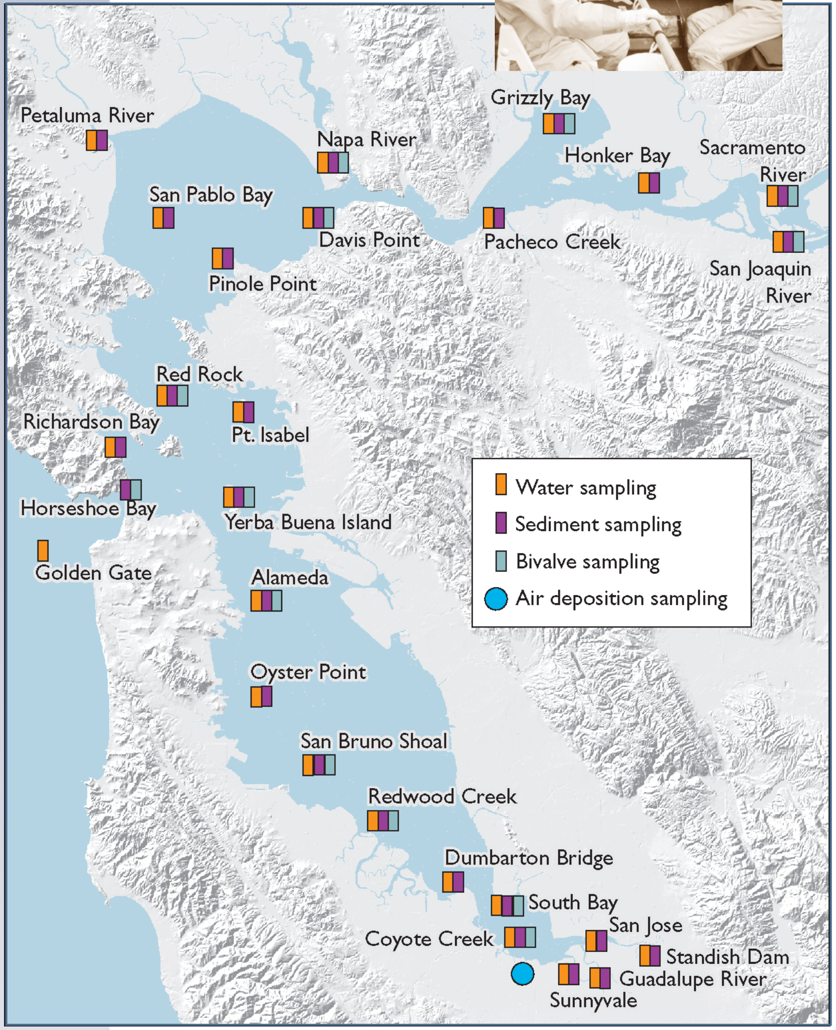
The RMP has produced a world-class dataset on estuarine toxic contamination. Monitoring performed in the RMP determines spatial patterns and long term trends in contamination through sampling of water, sediment, bivalves, and fish, and evaluates toxic effects on sensitive organisms and chemical loading to the Bay. The Program combines RMP data with data from other sources to provide for comprehensive assessment of chemical contamination in the Bay.

A portal to information about contamination in San Francisco Bay

The RMP provides information targeted at the highest priority questions faced by managers of the Bay. The RMP produces an annual report (the *Pulse of the Estuary*) that summarizes the current state of the Estuary with regard to contamination, a quarterly newsletter, technical reports that document specific studies and synthesize information from diverse sources, and journal publications that disseminate RMP results to the world's scientific community. The RMP web site provides access to RMP products and links to other sources of information about water quality in San Francisco Bay.

Water sampling

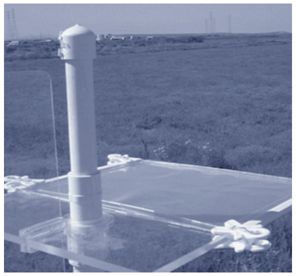
Sediment sampling

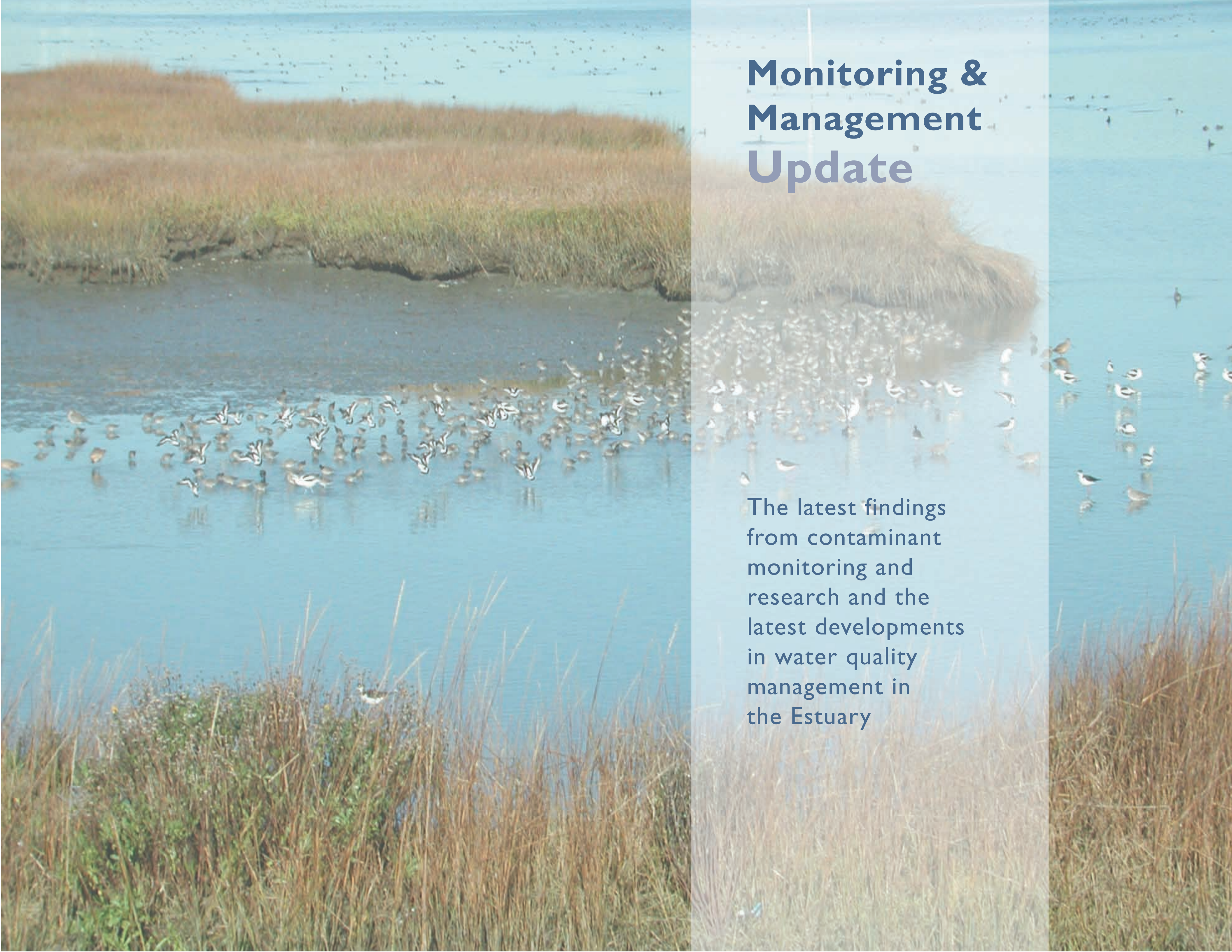


RMP Sampling Locations 2001

Bivalve sampling

Air deposition sampling





Monitoring & Management Update

The latest findings from contaminant monitoring and research and the latest developments in water quality management in the Estuary

Introduction

The **Status and Trends Update** is a presentation of graphical information on the present degree and distribution of contamination in the Estuary (status) and variation in contamination over time (trends). This summary incorporates the latest RMP findings, with a focus on the contaminants that are presently of greatest concern. In addition, this section includes data from studies outside the RMP. Inclusion of these other sources of information allows the *Pulse* to provide a more complete picture of contamination in the Estuary and its watershed. This issue includes a series of graphs from the U.S. Geological Survey (USGS) Ecology and Contaminants Project <http://wwwrcamnl.wr.usgs.gov/tracel/>. The USGS has conducted contaminant monitoring in the Estuary for many years. One emphasis of the USGS program has been evaluation of accumulation of trace elements in clams. Their monthly sampling complements the RMP by providing information on short-term variation that is essential to interpreting results from annual RMP sampling. Long-term monitoring by USGS is one of the primary sources of trend information for the Estuary. The CALFED Mercury Project is another important source of recent information on contamination in the Estuary, with a focus on the Delta–the freshwater portion of the Estuary. The CALFED Mercury Project was an intensive, multifaceted investigation of mercury sources, fate, and effects in the Delta. The two figures from the Project presented here illustrate the long-term persistence and broad spatial extent of the mercury problem in the Estuary and its watershed.

The **Current Status of Bay TMDLs** is an update on managing contaminants in the Estuary. The TMDL process is the regulatory framework used by the San Francisco Bay Regional Water Quality Control Board and stakeholders in the watershed to tackle the challenging problem of reducing the negative impacts of mercury, PCBs, and other priority contaminants on the Estuary.

CONTAMINANT GUIDELINES

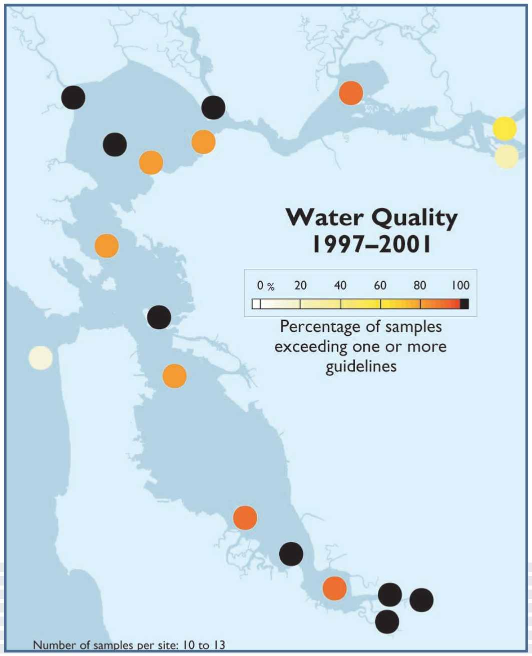
Contaminant guidelines* are generally intended to indicate if water or sediment is safe. Water and sediment are safe when those things we value (e.g., wildlife, being able to eat fish we catch, or ecosystem functions) are being protected.

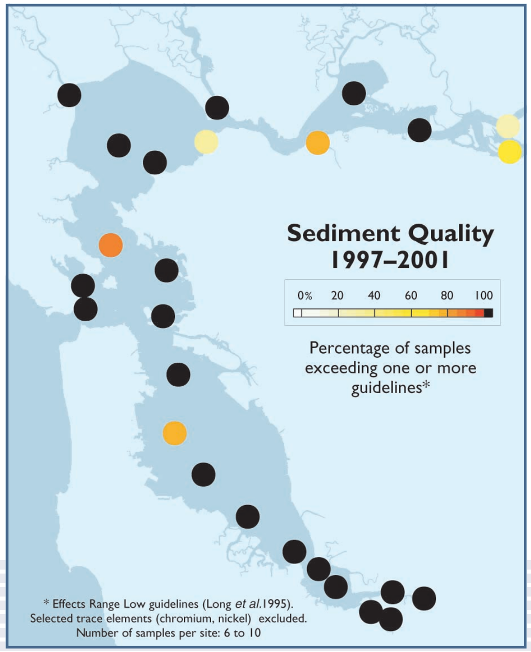
Guidelines provide a way to connect monitoring results, which are just numbers, with judgments on the condition of the environment. It is a daunting task to figure out just how high is too high when referring to contaminant levels in the Estuary. It is assumed that all organisms can tolerate some level of exposure to contaminants, but if that exposure gets too high, an "adverse effect," such as abnormal embryo development or death, will occur. Guidelines are set to protect Estuary wildlife and humans from adverse effects.

Continued on page 9

** In this report, the general term* guideline *is used to refer to several types of environmental quality benchmarks, from legally enforceable water quality criteria to unofficial benchmarks such as the Effects Range values for sediment (Long* et al. *1995).*

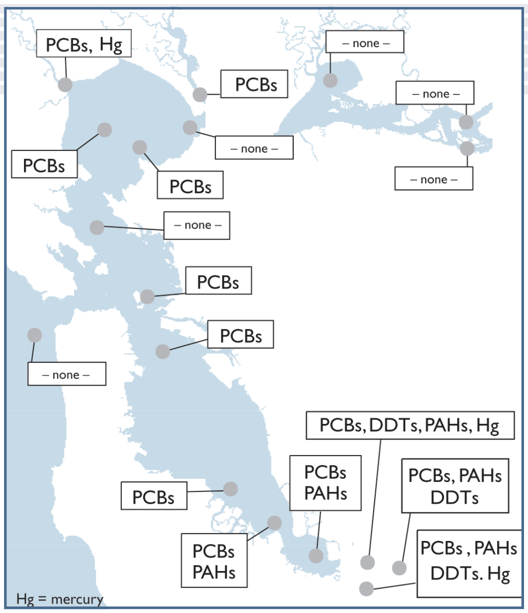
Status update



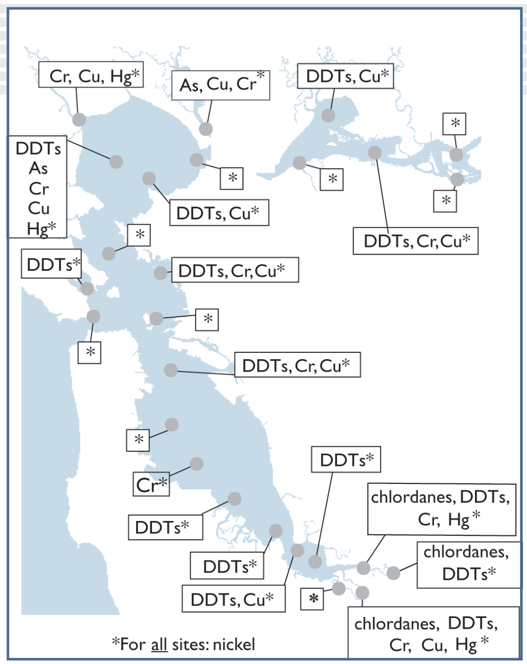


A few problem contaminants are widespread in the Estuary.

While the water and sediment of the Estuary meet cleanliness guidelines for most contaminants, a few problem contaminants are widespread. From 1997-2001, 61% of water samples analyzed in the RMP contained at least one contaminant at a concentration exceeding its water quality objective (top left). PCBs, PAHs, and mercury accounted for most of these exceedances (bottom left). For sediment, 90% of samples collected from 1997-2001 exceeded a threshold for possible effects on aquatic organisms (top right). Sediment contaminants that commonly exceeded their guideline included the organochlorine pesticides DDT and chlordane and the trace elements arsenic, chromium, copper, nickel, and mercury (bottom right). Contamination is not spread evenly throughout the Estuary. Overall, monitoring sites in the lower South Bay, the Petaluma and Napa River mouths, San Pablo Bay, and Grizzly Bay are more contaminated than other sites. The South Bay sloughs are particularly contaminated.

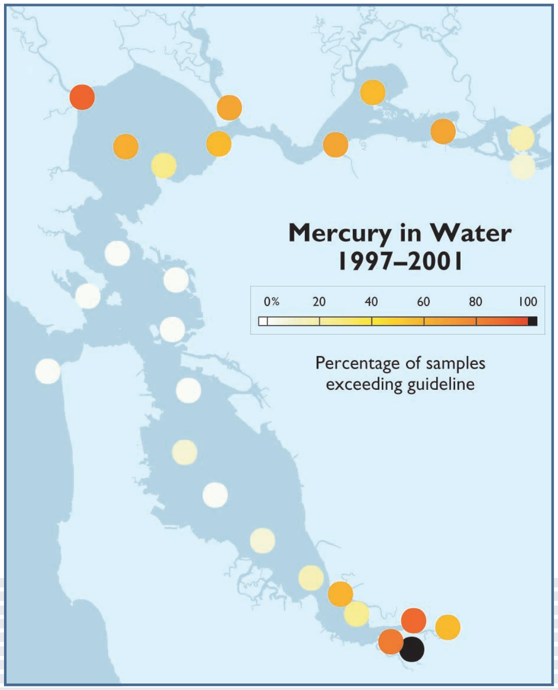


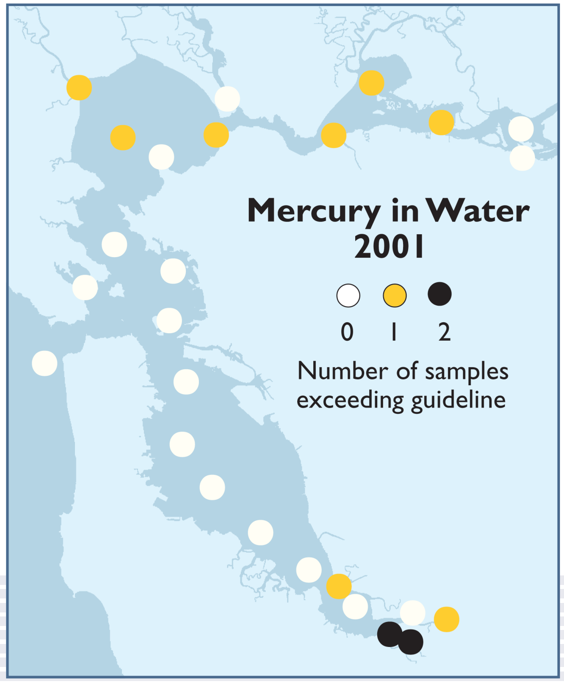
Water contaminants frequently (>90% of the time) exceeding their guideline (1997–2001)

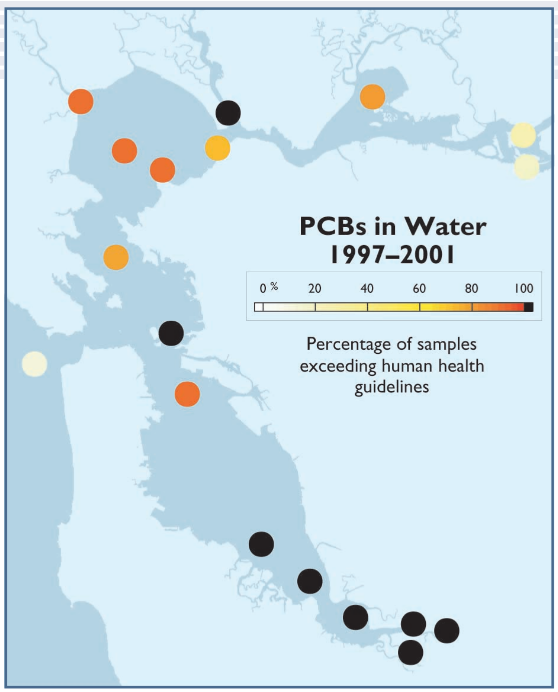


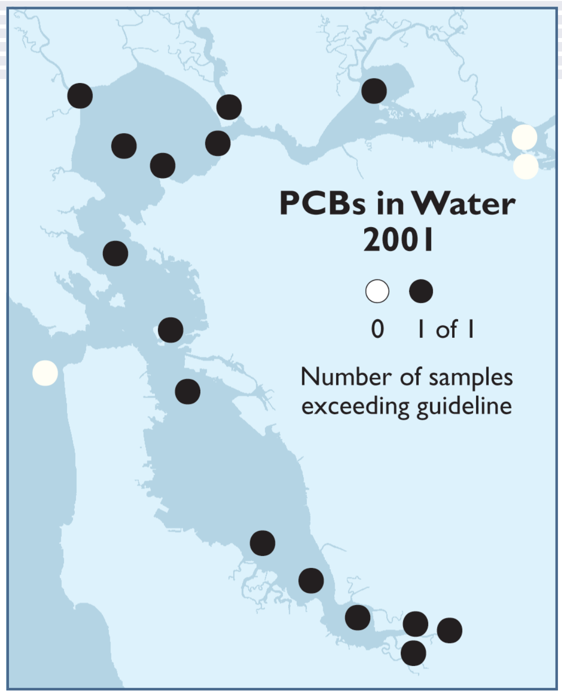
As=arsenic, Cr=chromium, Cu=copper, Hg=mercury, *=nickel

Sediment contaminants frequently (>90% of the time) exceeding their guideline (1997–2001).



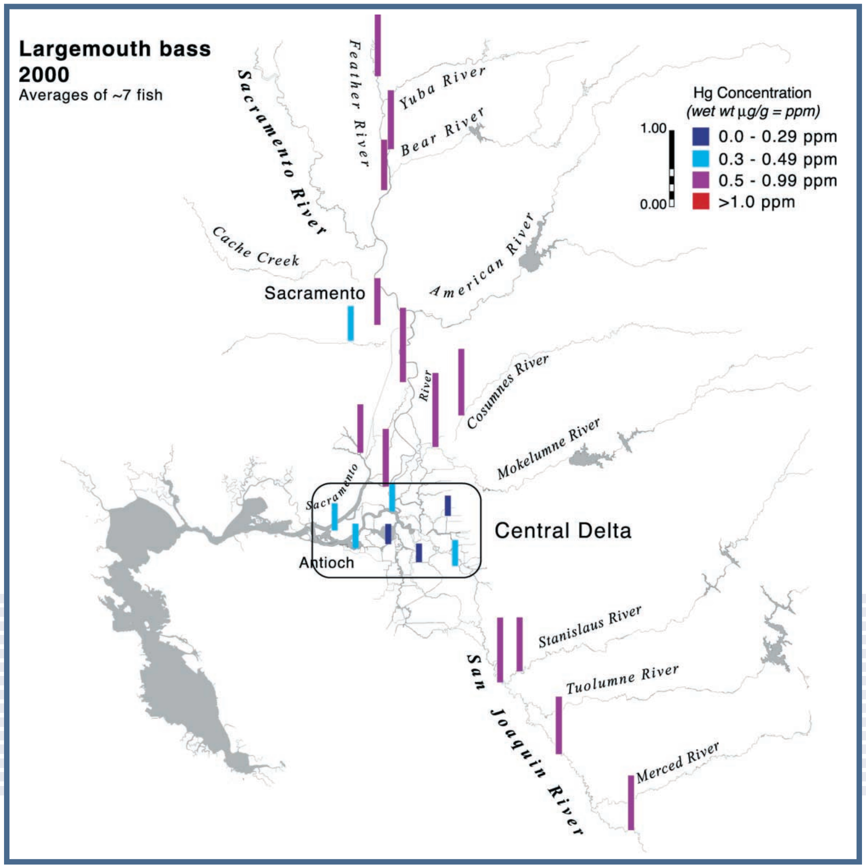


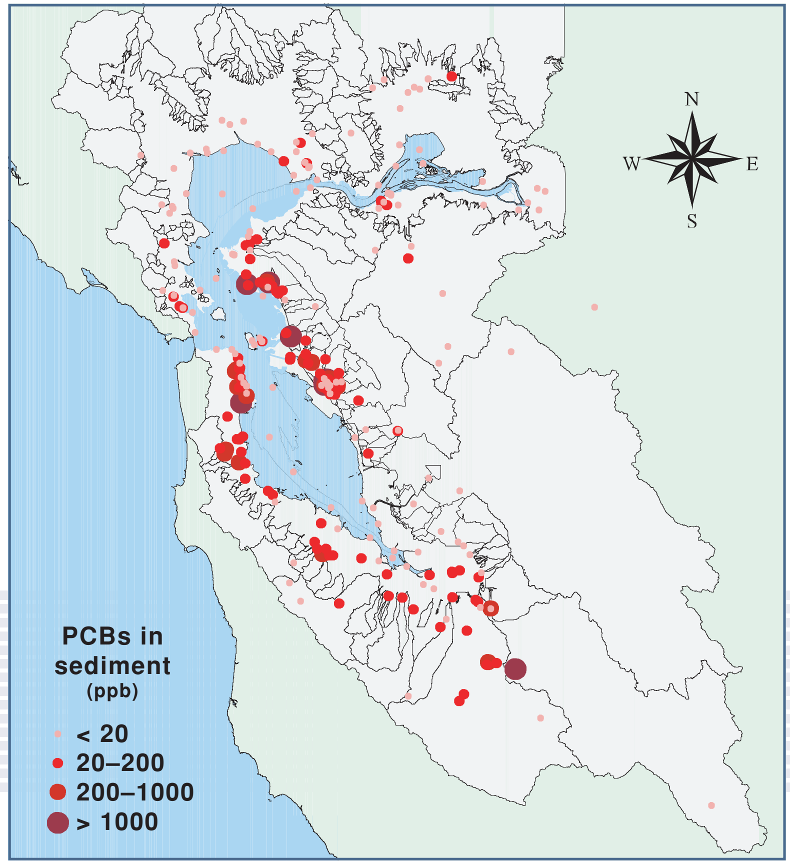




Mercury contamination is a major concern in the Estuary, and a high priority with the San Francisco Bay Regional Water Quality Control Board for clean-up action. Mercury is a problem because it accumulates to high concentrations in Estuary fish and wildlife. Humans and wildlife that consume Estuary fish face the greatest health risks due to mercury exposure. A water quality objective has been established for mercury that is designed to prevent accumulation of unacceptable concentrations in fish. The total mercury water quality objective was exceeded in 38% of samples collected from 1997 – 2001 (left) and 24% of the samples collected in 2001 (right). The RMP has consistently found elevated concentrations of mercury in water and sediment near the mouth of the Guadalupe River, attributable to the historic New Almaden mining district. The high concentrations of mercury observed near the mouth of the Petaluma River are due in part to the presence of a cloud of suspended sediment that is resuspended and deposited at this location with every tidal cycle (see Schoellhamer article page 21).

PCB contamination remains one of the greatest concerns in the Estuary, and is also a primary focus of clean-up efforts by the Regional Water Quality Control Board. Like mercury, PCBs are a problem because they accumulate to high concentrations in Bay fish and pose health risks to consumers of Bay fish. A water quality objective has been established for PCB concentrations in water to prevent unacceptable accumulation of PCBs in fish. This PCB water quality objective was exceeded in 79% of samples collected from 1997 – 2001 (left). PCB contamination is greatest in the South Bay; all samples collected in the South Bay during this period exceeded the objective. The original source of this contamination is not known. In 2001, 15 of 18 (83%) samples exceeded the objective (right).





The mercury problem extends to the freshwater portion of the Estuary

and through large portions of the Bay-Delta watershed. Largemouth bass is a popular sport fish species and a valuable indicator of mercury contamination in the freshwater portion of the Estuary. Mercury concentrations in largemouth bass in hundreds of river miles of the Sacramento and San Joaquin river basins have been found to be well above the 0.3 ppm threshold for potential human health concern. Some good news, however, is that concentrations in the central Delta are significantly lower and frequently below the 0.3 ppm threshold. The reason for the sharp drop in mercury in the central Delta waters is not yet understood. Other good news is that some other species, such as bluegill, generally do not accumulate mercury to concentrations of concern.

Reference: Davis, J.A., B.K. Greenfield, G. Ichikawa, and M. Stephenson. 2002. Draft report: Mercury in Sport Fish from the Delta Region. San Francisco Estuary Institute, Oakland, CA.

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

Local watersheds are important sources of PCBs to the Estuary.

Urban runoff from small tributaries around the Estuary has been identified as one of the main pathways for continuing input of PCBs. A recent survey of PCB contamination in sediment from creeks and storm drains (2000), when combined with sediment data from sampling in the Bay (1991–1999), begins to point to continuing sources of PCBs in the Bay watershed. These data can be reviewed in more detail and compared to land use and other information on the web at: <http://www.ecoatlas.org/custom/pcbtool.html>

Reference: McKee, L., Leatherbarrow, J., Newland, S., and Davis, J. 2002. Draft Report: A review of urban runoff processes in the Bay Area: Existing knowledge, conceptual models, and monitoring recommendations. SFEI Contribution 66. San Francisco Estuary Institute, Oakland, CA.

Contact: Jon Leatherbarrow, San Francisco Estuary Institute, jon@sfei.org

Trends update

Polychlorinated Biphenyls (PCBs)

PCBs are a group of over 200 organic chemicals with a number of characteristics that made them useful to industry. Manufactured from 1929 to 1979, PCBs were primarily used as hydraulic fluids, lubricants, plasticizers, in electrical transformers, and in carbonless copy paper. Smaller quantities were also used as pesticide extenders and in inks, waxes, and other products.

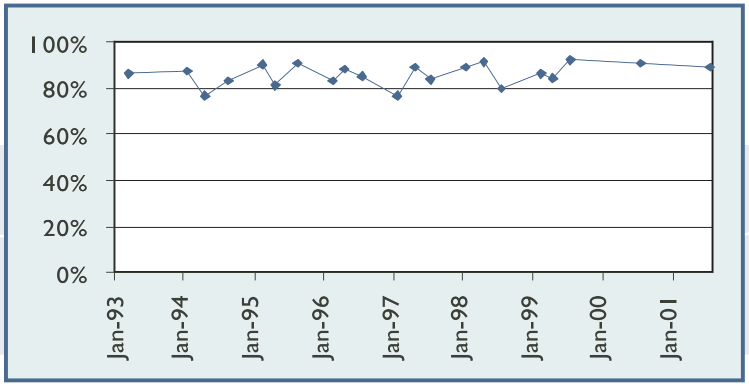
Growing awareness of the environmental impacts of PCBs, including their persistence and accumulation in animal tissue, led to a ban on their sale and production in the United States in 1979. Enclosed uses, such as in electrical transformers, are still permitted, and thousands of kilograms are known to be in use in the Bay Area. The bulk of the current PCB problem in the Estuary is believed to stem from activities prior to the 1979 ban.

PCBs are found at higher concentrations in animals that are higher in the food web. Therefore, predatory fish, birds, and mammals near the top of the food web, including humans that consume fish, are particularly vulnerable to the accumulation and effects of PCB contamination. Individual PCBs vary in their toxicity, but in general PCBs are extremely toxic in long-term exposures and can cause developmental abnormalities, disruption of endocrine system functions, impairment of immune function, and cancer.

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 is completely clean. There has been no obvious improvement in recent years. 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.

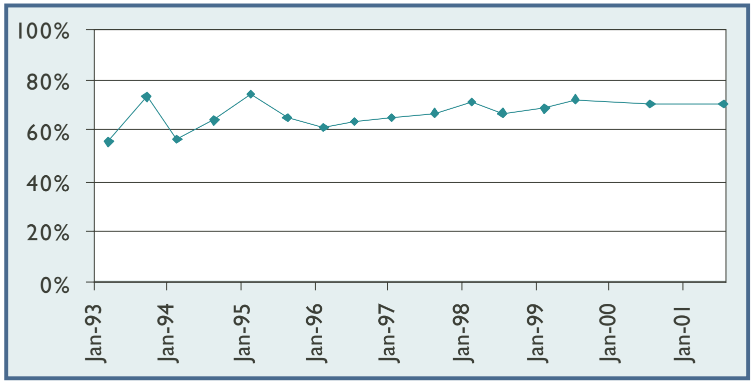
Water

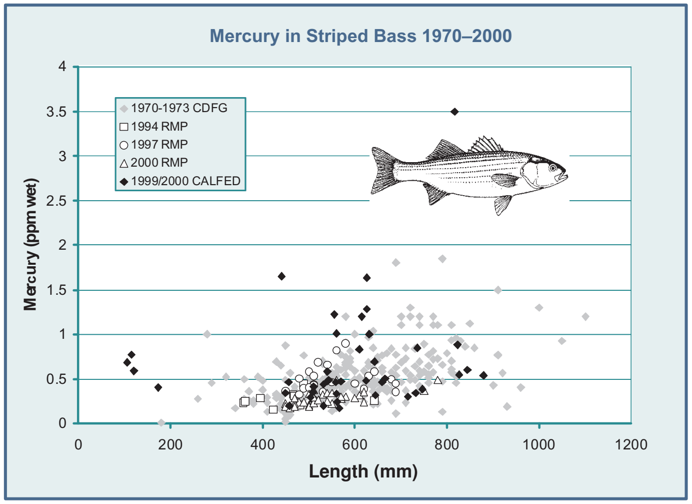


These charts were created by calculating, for each sampling period and contaminant, the percentage of samples that met the guideline. Results for each contaminant were then averaged within each sampling period to obtain the values plotted on the chart.

A value of 100% would mean all water or sediment samples met guidelines for all monitored contaminants.

Sediment



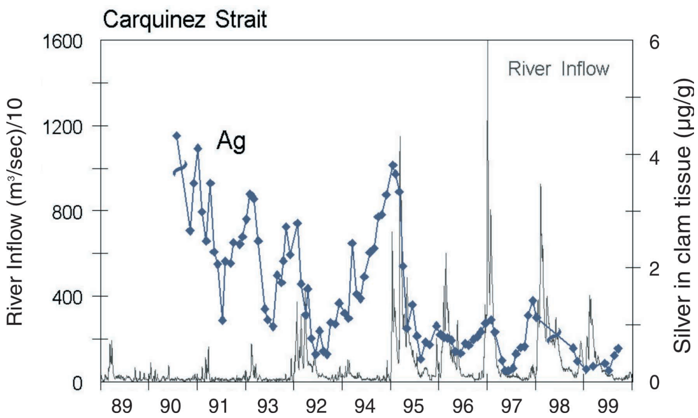


Mercury concentrations in striped bass from the Estuary have shown little or no change in 30 years.

One of the primary reasons for concern with regard to mercury is accumulation in Estuary sport fish and the associated fish consumption advisory. A consumption advisory related to mercury contamination in striped bass in the Estuary has been in place since 1970. In recent years the RMP and the CALFED Mercury Project have measured mercury in striped bass. These recent data can be compared to the data from the early 1970s. Size of the fish must be taken into account, as mercury reaches higher concentrations in larger, older fish. Mercury concentrations in samples collected in recent years are not appreciably different from the concentrations measured 30 years ago. In fact, some of the recently measured concentrations are high even relative to the historic data. These data suggest that the degree of mercury contamination in the Estuary food web is not declining.

Reference: Davis, J.A., B.K. Greenfield, G. Ichikawa, and M. Stephenson. 2002. Draft report: Mercury in Sport Fish from the Delta Region. San Francisco Estuary Institute, Oakland, CA.

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



Silver accumulation has been associated with reduced reproduction in clams.

Silver is not currently included on the 303(d) list of contaminants of concern, but a 2003 publication by U.S. Geological Survey researchers concluded that silver probably caused reduced reproductive activity in North Bay clams in the 1990s. The report was based on an excellent long term dataset showing trends in silver concentrations in clams (the exotic species *Potamocorbula amurensis*) from 1990 through 1999. Silver concentrations in the clams were found to be related to freshwater flows into the Estuary, with concentrations building up during dry periods and declining rapidly after major freshwater inputs. Monthly evaluation of reproductive status (gonad histology) found reduced reproduction when silver concentrations in the clams were above 2 µg/g dry weight. No other measured environmental variables appeared to be linked to the reduced reproduction.

Reference: Brown, C.L., Parchaso, F., Thompson, J.K., and Luoma, S.N. 2003. Assessing toxicant effects in a complex estuary: A case study of effects of silver on reproduction in the bivalve, Potamocorbula amurensis, in San Francisco Bay. Human and Ecological Risk Assessment 9: 95-119.

Contact: Cynthia Brown, U.S. Geological Survey, clbrown@usgs.gov

Continued from page 4

Of course, what is too high for some organisms may be perfectly tolerable for others. Natural factors also can have an influence; what is too high at one temperature or salinity may be tolerable at another. Contaminant mixtures can also act additively or synergistically, causing adverse effects even if the contaminant levels taken individually are safe.

Given these variables, setting a proper guideline is a challenging and inexact task. Guidelines can change as new information becomes available that indicates a guideline is not protective enough or is inappropriately low compared to natural concentrations. RMP results have helped determine if guidelines are set appropriately. Most guidelines were created for use throughout the state or nation, not specifically for the Estuary. Guidelines specific to the Estuary have been developed for some contaminants. For water, guideline development incorporates both laboratory studies and field observations, and is designed to protect a particular set of qualities we value, known in the California Water Code as "beneficial uses." Water quality guidelines are intended to protect most organisms most of the time, not all organisms all of the time. The Regional Water Quality Control Board, a state agency, sets water quality objectives with guidance from the U.S. Environmental Protection Agency. In 2000, the water quality objectives for the Estuary were revised. The revised values, collectively known as the California Toxics Rule, are used in this report. For a list

Continued on next page

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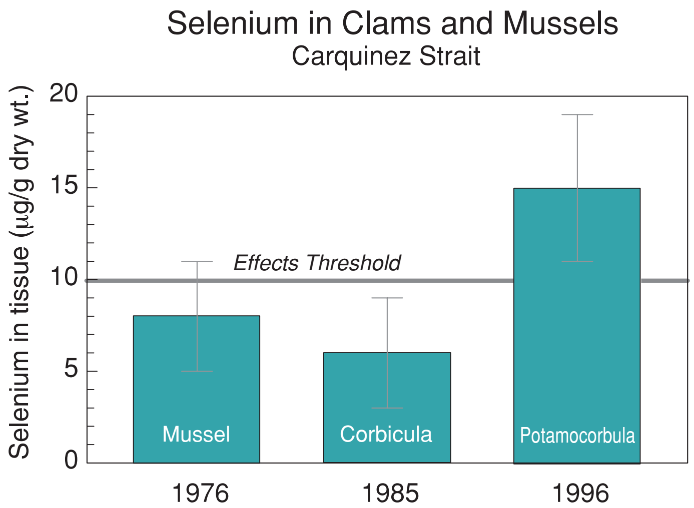
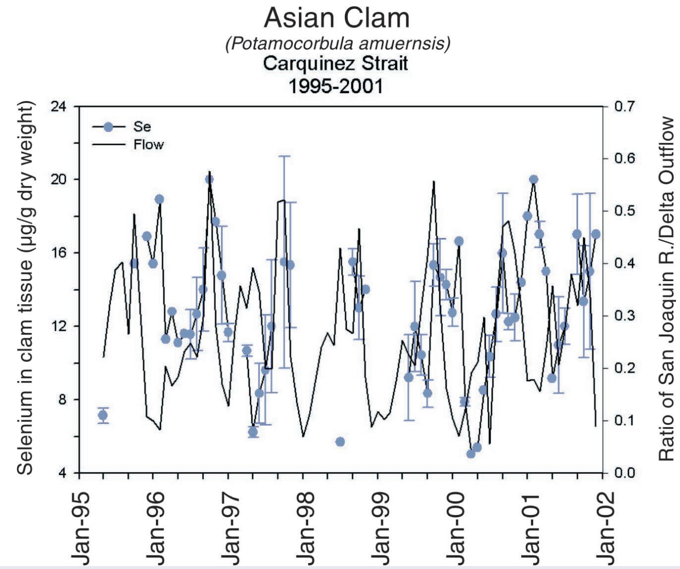
of the values, see <http://www.sfei.org/rmp/2000/2000_Annual_Results.htm>. For sediment, the guidelines used in the maps of this report ("Effects Range Low" or ERLs) are based on a study that compiled many observations of adverse effects on organisms in laboratories and natural settings around the world (Long et al. 1995). Using ERLs sets a high standard for Estuary cleanliness. For a list of the values, see <http://www.sfei.org/rmp/2000/2000_Annual_Results.htm>.





Changes in the aquatic community may increase selenium risks to wildlife and humans.

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. Consumption advisories for surf scoter and scaup have been in effect since 1986 and 1988, respectively, and this is a primary reason for the inclusion of selenium on the 303(d) list (see Inside Back Cover). A 2002 article by the U.S. Geological Survey (USGS) concluded that the invasion of the Bay by an exotic clam, *Potamocorbula amurensis*, that accumulates higher selenium concentrations than other bivalve species has increased the selenium threat to humans and wildlife. This clam has become a dominant member of the Bay food web and is an important prey item for surf scoters, sturgeon, and other species. The average selenium concentration in *Potamocorbula* in 1996 was well above the 10 µg/g dry weight threshold for possible effects on wildlife species consuming *Potamocorbula*.

Selenium concentrations in the northern Estuary fluctuate seasonally, but are not increasing or decreasing over the long term.

Understanding how bioaccumulation occurs in *Potamocorbula* is essential to evaluating the impact of future changes in selenium discharges to the Estuary. Since 1995, the USGS has measured selenium concentrations in *Potamocorbula* on a monthly basis to better understand factors influencing variability over time. Despite an overall reduction since 1998 in the concentrations of selenium in waters of the Estuary and in the proportion of the more bioavailable form of selenium ("selenite"), concentrations in *Potamocorbula* have not changed. Further studies are underway to determine the nature of the relationship between selenium inputs to the Estuary, river flow, and selenium uptake by *Potamocorbula*.

References for above figures:

Linville, R., Luoma, S.N., Cutter, L., and Cutter, G. A. 2002. Increased selenium threat as a result of invasion of the exotic bivalve Potamocorbula amurensis in the San Francisco Bay. Aquatic Toxicology 57: 51-64.

Contacts: Sam Luoma, U.S. Geological Survey, snluoma@usgs.gov, Robin Stewart, U.S. Geological Survey, arstewar@usgs.gov

The Current Status of Bay TMDLs

Dyan Whyte (dcw@rb2.swrcb.ca.gov) – San Francisco Bay Regional Water Quality Control Board, Oakland, CA

Total Maximum Daily Loads (TMDLs) are plans with numerical goals designed to attain and maintain water quality standards. The TMDL requirements set forth in the Clean Water Act require the San Francisco Bay Regional Water Quality Control Board (Regional Board) to develop solutions to San Francisco Bay's most challenging water quality problems. The overarching objective is to ensure that TMDL efforts result in tangible water quality improvements in the shortest possible time with the goal of restoring and maintaining the water quality standards of impaired waters. As such, the Regional Board strives to balance and optimize Regional Board staff efforts on the required elements of a TMDL within this perspective.

Baseline data from the RMP, RMP pilot and special studies, and studies funded by the recently formed Clean Estuary Partnership (CEP, see page 12) are invaluable for improving the technical basis of San Francisco Bay TMDLs and focusing implementation strategies towards actions that should truly make a difference. Each TMDL will include an adaptive implementation plan which sets forth feasible, reasonable, and effective actions that will lead to water quality improvements and identify studies needed to confirm key assumptions and resolve key uncertainties concerning fate, transport, and effects processes. Adaptive implementation is founded on the premise that implementing actions and observing the Bay response will provide the dual optimum benefit of defining effectiveness and improving our understanding of the Bay system.

The following discussion highlights progress and noteworthy findings on San Francisco Bay TMDL projects. Please visit <www.swrcb.ca.gov/rwqcb2/> for additional information on TMDLs and to obtain copies of TMDL reports.

Copper and Nickel

One positive outcome of the TMDL process can be a finding of no impairment and a subsequent delisting of a waterbody. This is the case for copper and nickel in San Francisco Bay. In February 2002, the State recommended removing all San Francisco Bay segments from the State's list of impaired waters (Clean Water Act 303(d) list, see Inside Back Cover) for copper and nickel. Bay-wide copper and nickel monitoring data, collected by the RMP over the last decade, helped to inform this finding. The South San Francisco Bay aspect of this decision exemplifies how stakeholder and Regional Board collaboration, coupled with the application of sound science and adequate funding, led to the development of site-specific objectives for San Francisco Bay and a finding that Bay waters do not exceed objectives. Another key to this success was the commitment by dischargers and stakeholders to implement preventive actions to assure that copper and nickel concentrations do not increase and that beneficial uses remain protected. A similar effort is underway for Bay segments north of the Dumbarton Bridge.

Mercury

The overarching goal of the San Francisco Bay mercury TMDL is to reduce mercury concentrations in biota such that fish, wildlife, and humans who consume Bay fish are protected. Regional Board efforts that began in 1998 are nearing completion with publication of a final TMDL report anticipated in spring 2003. Public comments received on this final report will be considered as key TMDL provisions are formally incorporated into the Basin Plan.

The final TMDL report proposes three numeric targets to define the solution to the San Francisco Bay mercury impairment problem: a fish tissue mercury concentration target to protect humans who consume Bay fish; an avian egg mercury concentration target to protect sensitive wildlife; and a sediment mercury concentration target to bring the Bay into compliance with water quality objectives. Meeting the proposed targets will require reducing mercury levels in sediment, fish, and bird eggs by about 50%.

The San Francisco Bay mercury implementation plan sets forth steps for achieving the TMDL targets and has four principal objectives:

1. reduce existing and future controllable discharges of mercury;
2. reduce the amount of methylmercury produced and the potential for bioaccumulation;
3. plot a course for addressing key scientific uncertainties and improve our understanding of the ecosystem; and
4. encourage actions that reduce loads of multiple pollutants.

Likely implementation actions include:

1. cleaning up the Guadalupe River and Central Valley watersheds mining legacies;
2. implementing BMPs and sediment control for urban runoff;
3. investigating the controllability of atmospheric deposition;

The Clean Water Act and TMDLs

The Clean Water Act recognizes that every body of water provides benefits that are valuable and worth protecting. The beneficial uses of a particular water body might include, for example, catching and eating fish, swimming, and drinking. Such uses require good water quality. Traditional management of water quality centers on maintaining standards for the cleanliness of wastewater. In some places this approach successfully protects the uses of a water body, but in others it does not. Water bodies that continue to lack the water quality necessary for supporting their designated uses are considered "impaired waters." Each state is required to develop a list of impaired waters and the contaminants that impair them (known as the "303(d) list," after the corresponding section of the Clean Water Act). Under the Clean Water Act, cleanup plans known as Total Maximum Daily Loads (TMDLs) must be developed for all impaired waters. The TMDL process takes a more comprehensive view of water quality by identifying all contaminant inputs to the water body, determining the total input the water body can handle, and designating particular inputs that need reduction.

4. reducing in-bay dredged material disposal; and
5. implementing measures to reduce the production of methylmercury.

RMP special studies and status and trends monitoring, and CEP-funded studies substantially improved the technical basis of this complex TMDL. The RMP's Mallard Island/Central Valley drainage contaminant load estimates, mercury atmospheric deposition study, estuarine sediment transport studies, and water and fish contaminant data sets all enhanced the scientific understanding of the problem and were used to propose TMDL mercury targets. The CEP studies are also playing a key role in identifying effective implementation actions. In the future, the Regional Board will rely on the RMP for ongoing monitoring and assessments to evaluate progress towards attaining TMDL targets and to help guide effective implementation actions.

PCBs

In addition to mercury, the Regional Board is concerned with PCB concentrations in San Francisco Bay fish and the threat they pose to human health and wildlife. A preliminary PCB TMDL report, anticipated for release in spring 2003, will describe water quality concerns and potential solutions. The Regional Board will encourage stakeholders to review this report and comment on the scientific basis of the technical TMDL and implementation alternatives.

PCB sources and loadings analyses suggest that the Bay ecosystem is dominated by the large amount of PCBs already in the sediments. Urban runoff and inflow from the Sacramento-San Joaquin Delta are estimated to be the major external loads to the system. A predictive model of the long-term fate of PCBs in the Bay developed under the RMP indicates that even small reductions in current PCBs loads will greatly accelerate the recovery of the Bay. A collaborative effort between SFEI (on behalf of RMP) and USGS is underway to enhance the modeling of the long-term fate of PCBs in the Bay that will better incorporate sediment dynamics and sources. SFEI has also collaborated with other scientists in a RMP effort to develop a Bay-specific food web model. This model should provide a predictive tool to relate sediment and water PCB concentrations to fish tissue PCB concentrations, and help focus our implementation actions.

The PCB TMDL implementation strategy will likely entail reducing PCB loads to the Bay by cleaning up contaminated sediments in storm drains and controlling future PCB discharges to storm drains from upland source areas, and by remediating contaminated "hot spots" on the Bay margin.

Other 303(d) Contaminants

San Francisco Bay is also listed as impaired due to selenium, legacy pesticides, diazinon, and although not formally listed, PBDEs and PAHs are on a watch list of contaminants that may soon emerge as a water quality concern (see Inside Back Cover). Through the RMP, the Regional Board hopes to track the status and trends of these pollutants. The CEP plans to develop simple conceptual models that reflect the scientific understanding of how these stressors move through the environment, compile existing data on the extent and severity of impairment, and develop lists of key management questions.

The Regional Board is finally realizing significant progress towards developing TMDLs, and for some pollutants, early implementation actions are underway. The Regional Board is confident that with continued assistance from the RMP and CEP and a collaborative stakeholder process we will achieve our goals.

Clean Estuary Partnership

The San Francisco Bay Regional Water Quality Control Board, the Bay Area Clean Water Agencies, and the Bay Area Stormwater Management Agencies Association have signed a Memorandum of Understanding reflecting their belief that a collaborative approach for developing TMDLs will be the most effective method for achieving sustainable water quality benefits for the Bay. The Clean Estuary Partnership (CEP) formed to implement the intent of this Memorandum of Understanding.

The mission of the Clean Estuary Partnership is to use sound science, adaptive management, and public collaboration to develop and implement technically valid and cost-effective strategies including TMDLs that result in identifiable, sustainable water quality improvements for San Francisco Bay. Please visit <www.cleanestuary.org> for more information about the CEP, to obtain copies of CEP reports, and to find out how you can become more involved in this program.

Feature Articles

Articles that examine the big picture of contamination in the Estuary, integrating information from the RMP and other sources into focused discussions on particular subjects

Introduction

In this issue and the next issue of the *Pulse* this section will contain articles that synthesize information from the past ten years of water quality studies of the Estuary. In this issue the focus is on the intensive monitoring of basic water quality parameters and toxicity that have been components of the RMP from the inception of the Program. Next year's issue of the *Pulse* will focus on results from long term monitoring of chemical concentrations in the water, sediment, and food web of the Estuary.

The U.S. Geological Survey (USGS) has been a partner in the RMP from the beginning, combining funding from RMP with other sources to provide detailed insights into ecological processes in the Estuary. USGS monitoring of basic water quality parameters (page 15) has documented significant long term changes in the ecology of the Estuary in the past ten years, including improvements in the oxygen content of Bay waters related to improved sewage treatment and the extraordinary impact of the invasive Asian clam (*Potamocorbula amurensis*) on the food web. This article was designated a Pulse Highlight because it provides a readily understandable introduction to the basic ecology of the Estuary.

Detailed USGS investigations of sediment dynamics in the Estuary and sediment supply from the watershed (page 21) have yielded important insights regarding contaminant fluctuations over the short term and fate over the long term. Sediment is becoming a scarce resource in the Estuary. Reduced sediment supply and increased demand for sediment from the Airport extension, the Cargill salt pond restoration project, and other large scale restoration projects will lead to erosion of sediment from the bottom of the Bay and possibly degrade water quality.

Researchers from the Granite Canyon Marine Laboratory, Pacific EcoRisk, and SFEI present a summary of ten years of toxicity testing on page 27. The frequent occurrence of toxicity in water and sediment of the Estuary has been a major concern. A management highlight from the past ten years is the observation of an apparent reduction in toxicity in water, possibly associated with reduced use of organophosphate insecticides. A new concern has arisen, however, over the possible ecological impacts of the pyrethroid insecticides that are being used as replacements for the organophosphates. The evolution of the toxicity testing element during the past ten years provides an excellent example of how the RMP has adapted to in response to changes in our state of knowledge and conditions in the Estuary.

Adaptation of the RMP is also the theme of an article summarizing the diverse array of Pilot and Special Studies conducted by the Program in the past ten years (page 32). These studies have produced a significant body of knowledge and provided an important mechanism for the Program to continually increase its relevance to managing contamination in the Estuary.

Lessons from Monitoring Water Quality in San Francisco Bay

James E. Cloern (jecloern@usgs.gov), Tara S. Schraga, Cary B. Lopez, and Rochelle Labiosa — U.S. Geological Survey, Menlo Park, CA

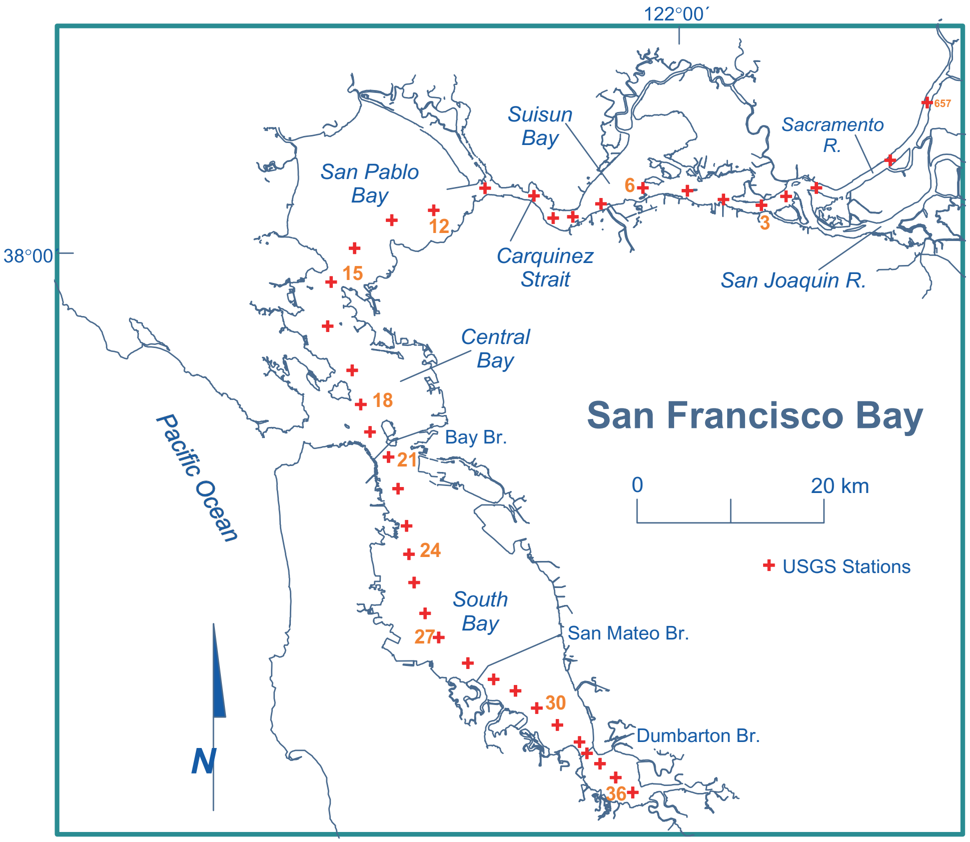


Figure 1. Monitoring of basic water quality parameters. The USGS, in cooperation with RMP, measures basic water quality indicators every month at 38 stations between the Sacramento River and South Bay with additional weekly sampling in the South Bay during spring. Submersible instruments measure salinity, temperature, suspended solids, light penetration, dissolved oxygen, and chlorophyll a from the water surface to the bottom. This basic information provides a foundation for understanding variability in the sources, transport, bioaccumulation, and ecosystem effects of contaminants in San Francisco Bay.

Introduction

San Francisco Bay is the defining landscape feature of the place we call 'The Bay Area,' but most of us only experience the Bay as we view it from an airplane window or drive across one of its bridges. These views from afar suggest that the Bay is static and sterile, but this impression is deceptive. If you are one of the many thousands of students who have experienced the Bay through a school excursion with the Marine Science Institute or other educational programs, you observed its rich plankton soup under a microscope, sorted clams and worms and crustaceans from mud samples, and identified the gobies, sole, halibut, bat rays, sharks, sardines, and smelt caught with trawls. San Francisco Bay is much more than a landscape feature. It is a dynamic ecosystem, continually changing and teeming with life. The Bay once supported the most valuable fisheries on the west coast of the United States, but commercial fishing for shellfish, shrimp, sturgeon, shad, salmon, and striped bass ended many decades ago because of habitat loss, pollution, invasive species and over harvest.

Bay Area residents feel a sense of responsibility to protect San Francisco Bay and keep it healthy. Some even dream about the recovery of fish stocks so they can sustain commercial fishing once again inside the Bay. How is our Bay doing? Is it highly polluted or pretty clean? How does its health compare with other estuaries in the United States? Are things getting better or worse? Does costly wastewater treatment have benefits? What are the biggest threats to the Bay and how can we reduce or eliminate those threats? How will the Bay change in the future? These questions can only be answered with investments in study and monitoring, and they are the driving force behind the Regional Monitoring Program (RMP). We describe here some selected results from water quality surveillance conducted by the U.S. Geological Survey (USGS) as one component of the RMP. We present results as lessons about how the Bay works as a complex dynamic system, and we show how these lessons are relevant to the broad RMP objectives supporting Bay protection and management.

The USGS-RMP Water Quality Monitoring Program

The RMP is one of several institutional investments to document and understand the changing condition of San Francisco Bay's living resources and water quality. The California Department of Fish and Game samples fish populations every month, and has maintained this invaluable Baywide monitoring since 1980 as a component of the Interagency Ecological Program <www.iep.water.ca.gov>. USGS scientists have studied physical, chemical, geological, and biological processes in San Francisco Bay since 1969, the longest continuing program of observation and study in a coastal ecosystem in the United States. The RMP filled a key gap when it became the first Baywide program to routinely monitor contaminants in water, sediments, and aquatic organisms, beginning in 1993. At its inception, the RMP established a partnership with USGS as a step toward the RMP objective of developing a complete picture of the sources, distribution, fate, and effects of contaminants in the Bay ecosystem.

The RMP is designed to detect trends of contaminant change over periods of years, but long-term trends can be difficult to identify or understand without knowledge of changes that occur over shorter time periods, within years. The function of USGS water quality monitoring within the RMP is to measure water quality indicators at weekly-to-monthly frequency to document changing Bay conditions over seasonal cycles and during events (floods, algal blooms, storms) that influence contaminant inputs, fate, and effects. This work builds a foundation of knowledge about Bay dynamics required to interpret trends measured in other RMP components. The USGS makes monthly measurements at 38 stations along the 145 km channel from the lower Sacramento River to the lower South Bay (Figure 1). Sampling is also done weekly in South Bay during spring when water quality is highly variable because of phytoplankton blooms. Measurements are made over the entire water depth with sensors for water temperature, salinity, suspended solids, chlorophyll a, and dissolved oxygen. Since 1993, the USGS has conducted 99 full-Bay and 175 South Bay sampling cruises, making over 61,000 measurements of each water quality parameter. Interested parties can download these data for their own analyses <http://sfbay.wr.usgs.gov/access/wqdata>. These data are used beyond the RMP: by marine-science teachers, students from elementary to graduate school, researchers around the world, consulting firms, and other government agencies. What have we learned about the Bay from this monitoring?

Oxygen as an Essential Element

A common impairment of coastal water bodies, such as Chesapeake Bay and the northern Gulf of Mexico, is depletion of dissolved oxygen from bottom waters. Oxygen depletion can kill fish and shellfish and exclude biota from large areas of habitat. Oxygen depletion is caused by microbial communities in water

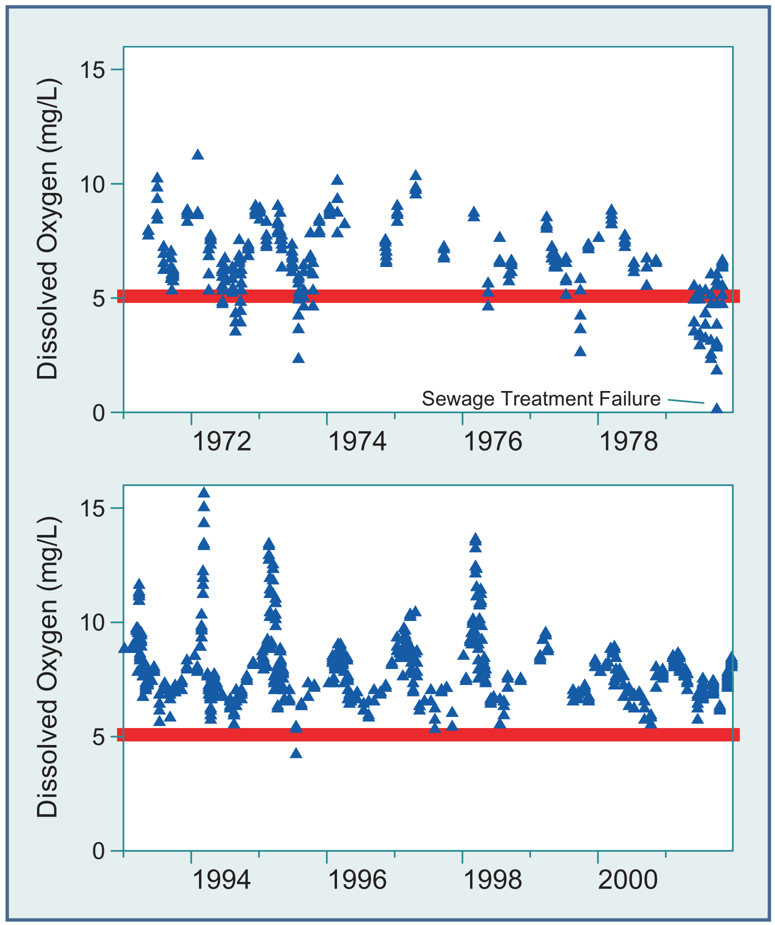


Figure 2. Oxygen conditions in the Bay have improved due to investments in wastewater treatment. Dissolved oxygen (DO) concentrations in San Francisco Bay nearly always exceed the 5 mg/L standard (red bar) protecting sensitive species of fish from oxygen depletion. The top panel shows bottom-water DO in lower South San Francisco Bay (USGS Stations 32-36) during the 1970s when summer DO episodically fell below the standard (note the disappearance of oxygen during the September 1979 disruption of sewage treatment). The bottom panel shows consistently high DO since 1993, reflecting improvements from advanced wastewater treatment that greatly reduced inputs of oxygen-consuming pollutants. San Francisco Bay is no longer impaired by low oxygen conditions.

and sediments as they respire to maintain their metabolism. Microbial metabolism depends on a supply of organic matter, and oxygen depletion occurs when the supply of organic matter exceeds the capacity of a water body to replenish oxygen. Organic matter comes either from direct inputs (e.g., of poorly-treated sewage) or from phytoplankton biomass produced from nutrients delivered by surface runoff or wastewater. Data collected by the USGS-RMP monitoring program since 1993 show that San Francisco Bay waters always have sufficient oxygen (> 5 mg/L) to sustain metabolism of the most sensitive fish species (Figure 2).

This was not always the case. In the 1950s and 1960s, before regulation of wastewater inputs by the 1972 Federal Clean Water Act, summer oxygen depletions were common, especially in the lower South Bay, which received large inputs of oxygen-demanding cannery waste and ammonia. Even in the 1970s, data collected by USGS showed episodic depletions of dissolved oxygen below 5 mg/L (Figure 2). The trend of steadily increasing dissolved oxygen and elimination of low-oxygen conditions is a compelling success story of water quality management, an example of benefits derived from investments in advanced wastewater processes that reduce inputs of oxygen-consuming wastes.

Monitoring allows regulators to identify and focus on pollutants posing the greatest threats

The past decade of USGS-RMP data provides strong evidence supporting a regulatory decision to remove San Francisco Bay from the list of California water bodies impaired by low oxygen. This illustrates how monitoring provides a scientific basis for prioritizing management actions so that regulatory efforts can identify and focus on pollutants posing the greatest threats to water quality and human and ecosystem health. Continued vigilance through monitoring is essential, however, because events remind us that the oxygen content of water can still disappear rapidly following high organic inputs. In September 1979, the South Bay basin below the Dumbarton Bridge was oxygen-depleted and regions were devoid of fish and shrimp for several weeks (prompting the news headline *Sewage Leaves Bay a 'Dead Sea'*), following inputs of primary-treated sewage during a disruption of the San Jose-Santa Clara Waste Treatment Facility (Cloern and Oremland 1979).

The Bay as an Open Ecosystem

San Francisco Bay is connected to large rivers, urban watersheds, and the coastal Pacific Ocean. The Bay is profoundly influenced by inputs from these three connections, each having its own chemical makeup and distinct variability. Salinity in the Bay is a simple indicator of river-runoff inputs, and salinity measurements before and after the 1997 New Year's Flood showed remarkable changes in the composition of Bay water (Figure 3). Average salinity dropped from 26.1 to 9.0 psu (the salinity of fresh water is 0 psu and the salinity of seawater is 35 psu), so the Bay as a whole changed from 79% seawater to only 27% seawater. Salt dilution of this magnitude shows that more than half the Bay's water volume was displaced by river inflow between November 1996 and January 1997. During these periods of high inflow, concentrations of runoff-derived contaminants (e.g., chromium, nickel) increase, and concentrations of locally-derived industrial contaminants (e.g., silver) decrease in clam tissues (Brown and Luoma 1999; Brown et al. 2003). The availability of some metals (e.g., cadmium) for uptake by aquatic organisms varies with salinity, so salinity monitoring provides essential information for understanding changes in organism contamination.

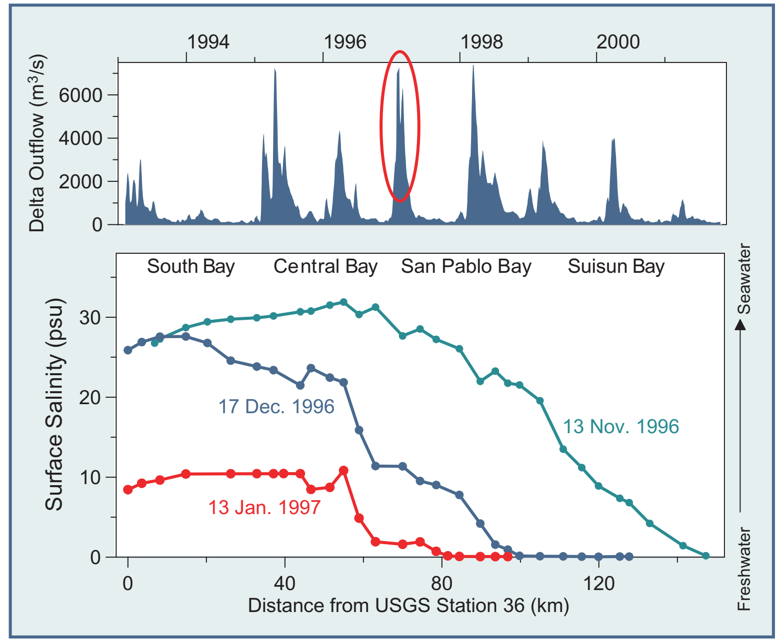


Figure 3. The Bay is profoundly influenced by water inputs from the Delta. Salinity measures the relative proportions of freshwater and seawater in an estuary, a key environmental factor for interpreting changes in the sources, concentrations and biological availability of toxic substances. Winter floods replace brackish Bay water with freshwater, diluting some contaminants (e.g., silver) and delivering others (e.g., mercury, PCBs). The bottom panel shows salinity along the Bay during three sequential USGS monitoring cruises to illustrate Baywide displacements of salt when Delta outflow increased in December 1996 and peaked during the 1997 New Year's flood. The top panel shows 1993-2001 Delta Outflow (California Department of Water Resources), highlighting this flood event. (Delta outflow is plotted as a 7-day average to smooth the large daily variability.)

The Pacific Ocean is another powerful force of change, and we can use other indicators to study the influence of oceanic processes on the living Bay system. In September 2002, patches of colored water were observed in Central Bay; microscopic analyses revealed that the 'red tide' was a bloom of *Heterosigma akashiwo.* This harmful alga has never been reported in the Bay before, and its presence is reason for concern because it is associated with fish kills in Puget Sound and other coastal ecosystems. Causes of the *Heterosigma* bloom in San Francisco Bay are a mystery, but satellite imagery suggests that it originated offshore and propagated into the Bay. A satellite image from SeaWifs (Figure 4) shows an abundance of phytoplankton (chlorophyll a) offshore on September 16, 2002, consistent with reports of red tides off Stinson Beach and Bodega Bay. This image clearly depicts the Bay's ocean connection and the lesson that water quality and living resources inside the Bay are influenced by events outside the Golden Gate, just as they are influenced by inputs from the rivers and urban watersheds. Lessons from monitoring teach that the Bay is an open system that responds to change at its boundaries.

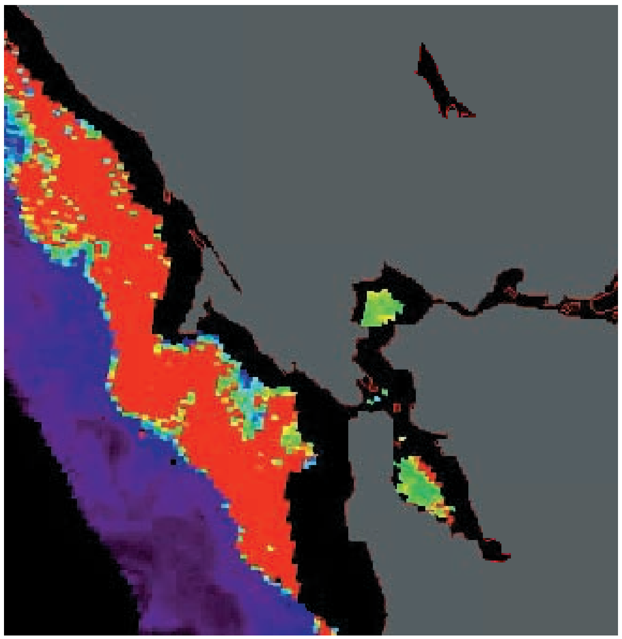


Figure 4. Water quality and living resources inside San Francisco Bay are influenced by events outside the Golden Gate. This satellite (SeaWiFS) image from September 16, 2002 shows high quantities of phytoplankton (microscopic algae) as red in the nearshore Pacific Ocean. At the same time, a red tide bloom of a toxin-producing species of phytoplankton was observed inside San Francisco Bay. [Black indicates no data, typically due to the presence of land or clouds. Color inside San Francisco Bay is not accurate because of interference by suspended sediments.]

Phytoplankton as Food Resource and Contaminant Carrier

The largest living component of San Francisco Bay is invisible to the naked eye – the suspended microalgae, or phytoplankton. Phytoplankton photosynthesis is the most important energy supply to Bay-Delta foodwebs (Jassby et al. 1993; Sobczak et al. 2001), supporting clams, worms, shrimp, zooplankton, herring, sturgeon, striped bass, canvasback ducks, pelicans and, ultimately, harbor seals. Phytoplankton photosynthesis in the Bay produces about 120,000 tons of organic carbon each year, or the number of calories required to sustain over a million adult humans. This food supply is smaller than average for the world's estuaries (partly because the Bay is turbid), and as a result phytoplankton consumers such as zooplankton, mysid shrimp and clams are usually limited by the available supply of food. Food limitation disappears during phytoplankton blooms, when phytoplankton biomass becomes high enough to sustain maximum rates of growth and reproduction by these consumers (Cloern 1996).

Phytoplankton production also transforms dissolved chemicals (carbon dioxide, nitrate, phosphate, trace metals, organic molecules) into particulate forms (algal cells) that can be consumed by organisms at the next trophic level. This transformation is the entry point of contaminants into foodwebs, including priority pollutants such as selenium, mercury, and PCBs that increase to potentially toxic levels as they are transferred up the food chain. Because phytoplankton production and transformation of trace metals accelerate during blooms (Luoma et al. 1998; Beck et al. 2002), these events act as biological regulators of the toxicity and accumulation of contaminants in Bay foodwebs.

Phytoplankton monitoring at weekly-monthly frequencies reveals seasonal patterns such as the prominent spring bloom that occurs every year in South Bay (Figure 5), whereas continuous monitoring with moored instruments enables us to measure short-term variability between ship-based samplings. Sustained monitoring over decades shows that there has been a change in the annual pattern from a spring bloom cycle to a spring and autumn-winter bloom cycle in the South Bay (Figure 5). This recent departure from a 21-year pattern suggests that the South Bay has experienced a regime shift, for reasons not yet identified. Clues might come from a recent study showing multi-decade biological cycles around the Pacific Basin (Chavez et al. 2003). Could the recent appearance of autumn-winter blooms inside San Francisco Bay reflect a Pacific-scale regime shift? Records from a moored fluorometer (Figure 5) show that chlorophyll varies within a day, sometimes over a range comparable to that measured over seasons or decades. This record shows two peaks per day suggesting a tidal process such as oscillation of water masses containing patchy chlorophyll distributions (Jassby et al. 1997). Lessons from phytoplankton monitoring show that San Francisco Bay is a continually-changing and evolving biological system, over periods from hours to decades. An important challenge of monitoring design is to measure and understand variability at all time scales so that trends of long term change can be detected and interpreted with confidence.

Biological Pollution as Damaging as Chemical Pollution

San Francisco Bay's biological communities are a mix of native and alien species, and some habitats are dominated by aliens. Many species were introduced into the Bay long before monitoring began, so we have no knowledge of the Bay's biological community structure, water quality, or ecosystem functions prior to species introductions by humans. Monitoring in recent decades has provided direct measures of the disturbance caused by alien species. A compelling example is the suite of changes in northern San Francisco Bay that followed, almost immediately, invasion by the Asian clam *Potamocorbula amurensis*. Prior to this invasion in 1986, phytoplankton in Suisun Bay accumulated to high levels in summer (Figure 6). These summer blooms did not appear in 1987 and they have been absent since. *Potamocorbula* filter phytoplankton from water, and they are abundant enough to remove algal cells faster than phytoplankton can reproduce in Suisun Bay. As a result, *Potamocorbula* has reduced primary production five-fold (Alpine and Cloern 1992), creating an environment of chronic food limitation for consumers. Populations of the native shrimp, *Neomysis mercedis*, have nearly collapsed in Suisun Bay and one explanation is depletion of the phytoplankton food resource by *Potamocorbula* (Orsi and Mecum 1996). Similar changes occurred in the crustacean zooplankton communities, so the Interagency Ecological Program (IEP) and USGS monitoring have documented the disruption of communities and ecosystem functions caused by this alien species. Analysis by the Regional Water Quality Control Board concludes that "Exotic species are one of the greatest threats to the integrity of the San Francisco Estuary ecosystem, perhaps as great as any pollutant regulated under the Clean Water Act." Monitoring of biota and measurements of ecosystem functions provide a sound scientific basis for inclusion of exotic species on the 303(d) list of pollutants that impair San Francisco Bay (see Inside Back Cover).

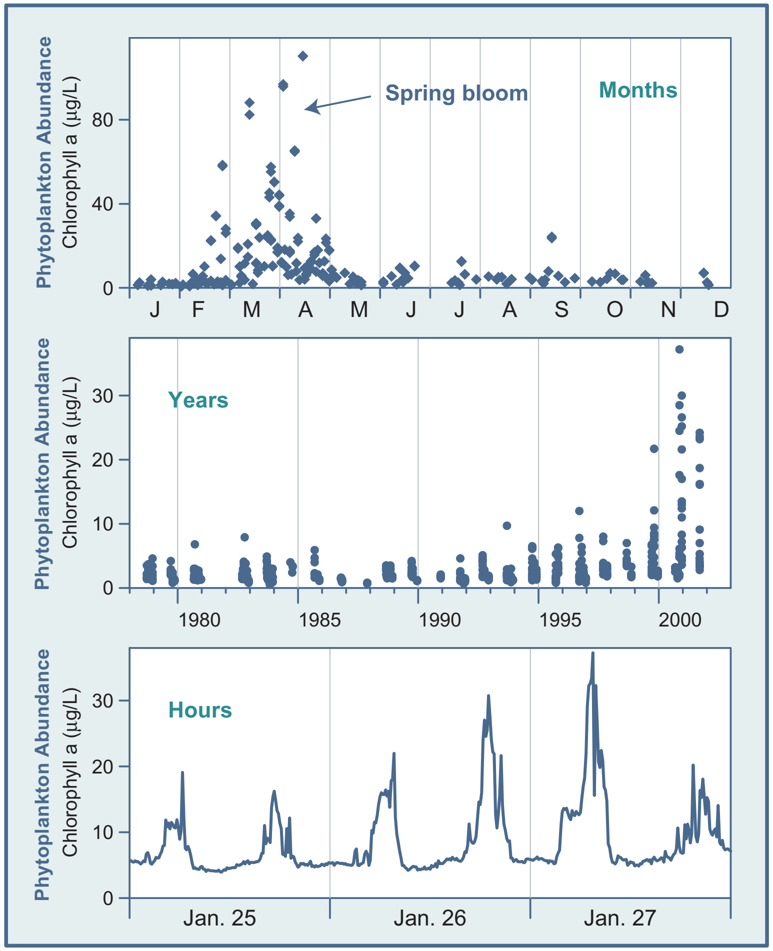


Figure 5. Long-term monitoring has revealed fundamental shifts in seasonal cycles of the Estuary's food supply. Phytoplankton (microscopic, suspended algae) is the largest living component of the San Francisco Bay ecosystem, and phytoplankton photosynthesis is the biological engine that fuels food webs, transforms contaminants, and moves contaminants such as selenium, mercury, and PCBs into food webs. These figures illustrate variability of phytoplankton abundance (as measured by chlorophyll a concentration) at three time scales: the top panel shows monthly variability near the Dumbarton Bridge from 1993-2001, highlighting the spring bloom that typically develops between mid February and mid April. The middle panel shows all measurements made in South San Francisco Bay during September-December from 1978-2002, suggesting a regime shift to autumn-winter blooms beginning in 1999. The bottom panel shows chlorophyll near the Dumbarton Bridge measured every ten minutes during 3 days of January 2003. Comprehensive monitoring documents variability at all these time scales, each of which may be important in understanding water quality in the Bay.

The Need for Comprehensive Monitoring

The lessons described here illustrate how monitoring contributes to resource management. For San Francisco Bay, monitoring data provide the basis for establishing water quality management priorities that have evolved over time and now focus on nonpoint sources of pollution, exotic species, and a prioritized set of toxic contaminants. Monitoring records changes in the chemical and biological condition of San Francisco Bay, providing an objective basis for measuring the benefits of advanced wastewater treatment and point-source reductions of toxic pollutants. It can similarly document responses to future actions such as steps to reduce pollutant loadings from nonpoint sources. Finally, monitoring data provide powerful clues revealing how San Francisco Bay functions as an ecosystem and how its functions respond to both natural forces and human activities.

The need for monitoring information is perpetual because San Francisco Bay will continue to change in ways we cannot predict. We can, however, identify forces of change that might reshape the Bay ecosystem, such as: conversion of salt ponds to new habitats; construction of airport runways; climate changes that alter the seasonal timing and quantity of river runoff; sea level rise; population growth adding over 1.4 million Bay area residents by 2020 <http://www.dof.ca.gov/>; unanticipated introductions of new species; and regulatory actions such as implementation of TMDLs. Although we know with certainty that San Francisco Bay will change in coming decades, there is no institutional framework to fully document, understand and support adaptive management to those changes. The USGS-RMP partnership illustrates how resources of two institutions can be combined to meet some specific monitoring needs, but the full suite of potential partnerships has not been melded into a Baywide comprehensive monitoring program.

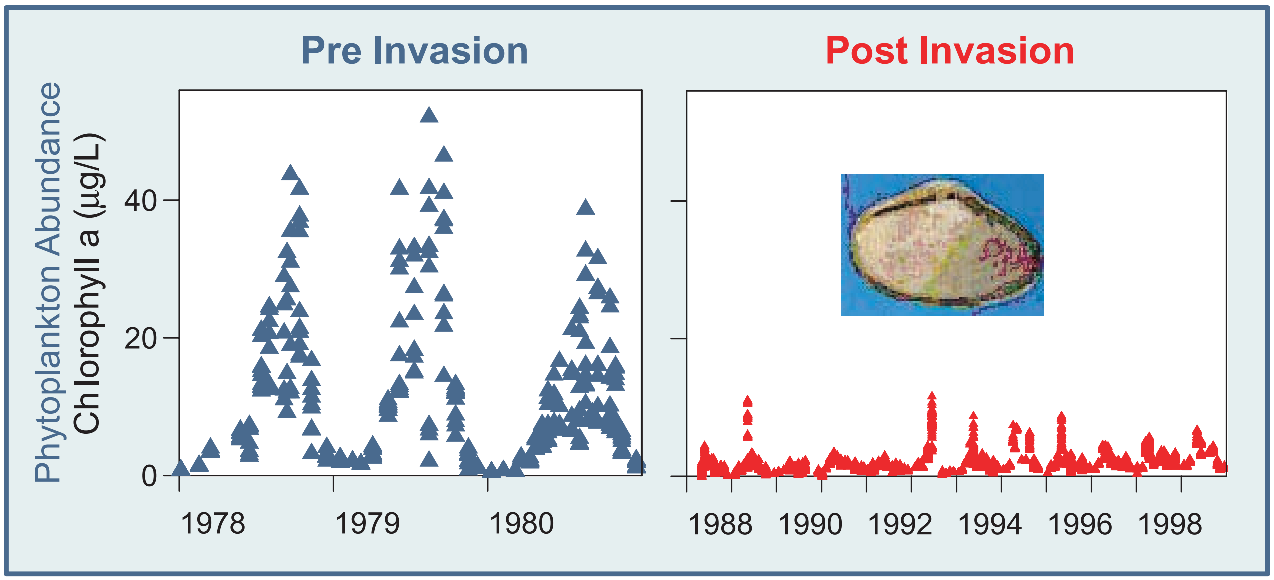


Figure 6. Ecosystem disruption from biological pollution can be as powerful as disruption from chemical pollution. The summer phytoplankton bloom disappeared and abundance and photosynthetic production decreased fivefold in Suisun Bay after invasion by the alien clam *Potamocorbula amurensis* in late 1986. This Figure compares annual cycles of phytoplankton abundance (chlorophyll a) in Suisun Bay for three years before (left panel) and 12 years after this invasion (right panel). The mean pre-invasion (1978-1980) chlorophyll concentration was 9.8 mg/L compared to the mean post-invasion concentration of 2.1 mg/L. Native invertebrates, including important forage species for fish, are now food-limited and populations of some species (the mysid shrimp *Neomysis mercedis*) have virtually collapsed since this invasion.

Our ability to anticipate and document future change in the Bay is deficient in four areas. First, institutional commitments to biological monitoring do not support regular sampling of plankton, sediment-dwelling invertebrates, waterfowl, or mammals. Basic components of water quality such as nutrients, and ecosystem functions such as primary production, are also missing from the existing monitoring effort (IEP monitors nutrients and lower trophic level organisms, but not Baywide). Second, there is no mechanism for integrating and synthesizing information collected by agencies conducting specialized monitoring or research. Data are archived in disconnected databases, and cross-program data synthesis and integration are not supported institutionally. These deficiencies limit our progress toward an ecosystem-scale perspective of the Bay's systemic responses to changes in land use, habitats, waste loadings, climate, and invasive species. Third, existing programs do not fully exploit new technologies such as remote sensing and real-time data collection with moored instruments to measure changes at the spatial and temporal scales missed by ship-based sampling. Finally, institutional commitments have not been made to design, implement and permanently fund a comprehensive monitoring assessment and research program (CMARP), although the need is widely recognized and a general roadmap has been produced <http://www.iep.water.ca.gov/cmarp/>.

Given the value of monitoring to resource management and the certainty of forces that will change San Francisco Bay in uncertain ways, we wonder: How might the monitoring lessons described here be applied to stimulate implementation of a CMARP?

Sediment Dynamics Drive Contaminant Dynamics

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Jay A. Davis, and Lester J. McKee – San Francisco Estuary Institute, Oakland, CA

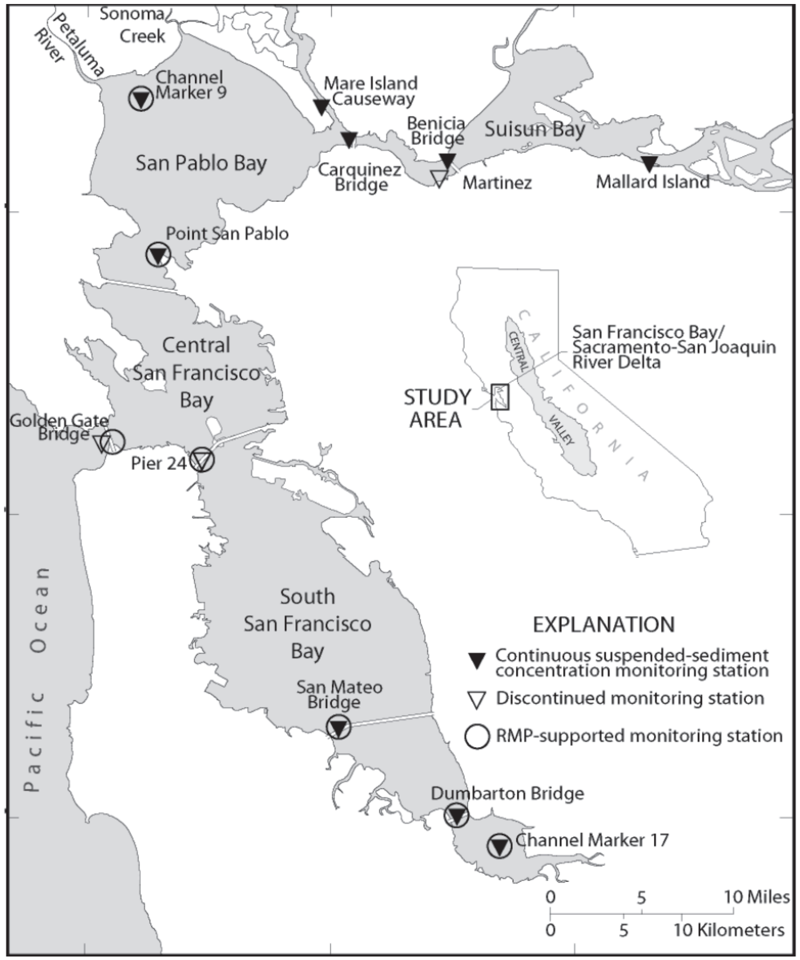


Figure 1. Suspended sediment concentration monitoring stations in San Francisco Bay. Monitoring stations have been established in each major region of the Bay. Funding for this network is provided by RMP, USGS, and many other entities.

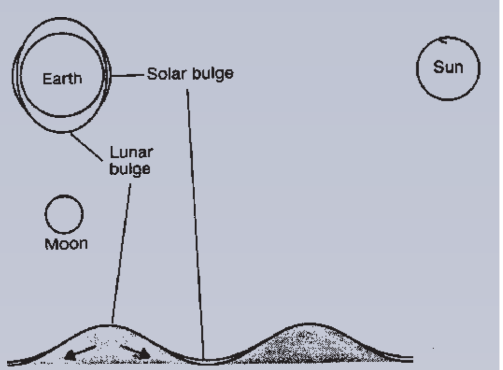
Introduction

Many contaminants of greatest concern in San Francisco Bay, including mercury and PCBs, are primarily associated with sediment particles rather than dissolved in water. Therefore, the movement and fate of sediment determines the movement and fate of many contaminants in the Bay. Because of this close association, the RMP monitors and seeks to understand the quantity and movement of sediment suspended in the water. Through study of suspended sediment dynamics, the RMP is developing a better understanding of trends and patterns of contaminants and how the Bay will respond to management actions during the next several decades. Recent RMP efforts to develop predictive models of contaminant fate in the Bay have highlighted the fundamental importance of understanding sediment dynamics.

Sediment movement in the Bay is determined by tides, wind, and freshwater inflow. Tides flood and ebb twice a day, wind typically is strongest in the afternoon, and freshwater inflow is greatest during the winter rainy season (see sidebar on next page). To characterize these fluctuations, the U.S. Geological Survey (USGS) began continuous monitoring of suspended sediment concentration in 1991. Continuous suspended sediment concentration monitoring stations were established in each major region of San Francisco Bay (Figure 1), establishing a continuous monitoring network. The sensors at each station measure the amount of material in the water every 15 minutes. Results are available on the internet at <http://sfports.wr.usgs.gov/Fixed_sta/>. In addition to the network, sensors have been deployed at as many as 14 additional sites in the Bay for periods of several months as part of focused studies of sediment transport in Bay locales of special interest.

Many Priority Contaminants are Closely Associated with Sediment Particles

Sediment becomes suspended in the water column through a variety of physical processes and transports associated contaminants around the Bay. For example, mercury is a contami-



The gravitational pull of the sun and moon generates tides with flood (landward) and ebb (seaward) currents. The rotation of the earth and moon create in San Francisco Bay two flood and ebb tides every 24.8 hours. Tidal currents are strongest during full and new moons, called spring tides, and weakest during half moons, called neap tides. As a result, suspended sediment concentrations are larger during spring tides than during neap tides (Figure 3).

nant of concern because of its toxicity and tendency to bioaccumulate in the food web. The vast majority of mercury in the Bay is a legacy of mercury mines in the Bay Area, especially in the Guadalupe River watershed in South Bay, and from hydraulic mining for gold in the Sierra Nevada. Because mercury samples are expensive to collect and analyze, it is desirable to find a proxy that can be sampled easily and inexpensively. Suspended sediment fills this role. RMP data collected from 1993-2000 at five sites in San Pablo Bay show that mercury concentrations were closely related to suspended sediment concentration (Figure 2). Ninety-one percent of the variation in the mercury concentration can be explained by variation in suspended sediment concentration.

Using this linear relation, continuous total mercury concentration can be estimated from continuous suspended sediment concentration data. Figure 3 shows the suspended sediment and estimated total mercury concentrations at Point San Pablo during water year 2000. The record is highly variable through the year, reflecting physical processes such as the spring-neap and diurnal tidal cycles, rainfall and runoff and associated variance in concentrations and loads, and wind-wave resuspension of bottom sediment. The strongest signals are caused by increased sediment supply during the rainy season (October through April) and resuspension and transport of bottom sediments during energetic spring tides.

Water Quality Objective for Mercury Exceeded When Suspended Sediment Concentration is Large

The San Francisco Bay Regional Water Quality Control Board has set a water quality objective for total mercury concentration of 25 ng/L averaged over any four-day period. A time series of the estimated mercury concentration can be used to evaluate how often that objective was met from

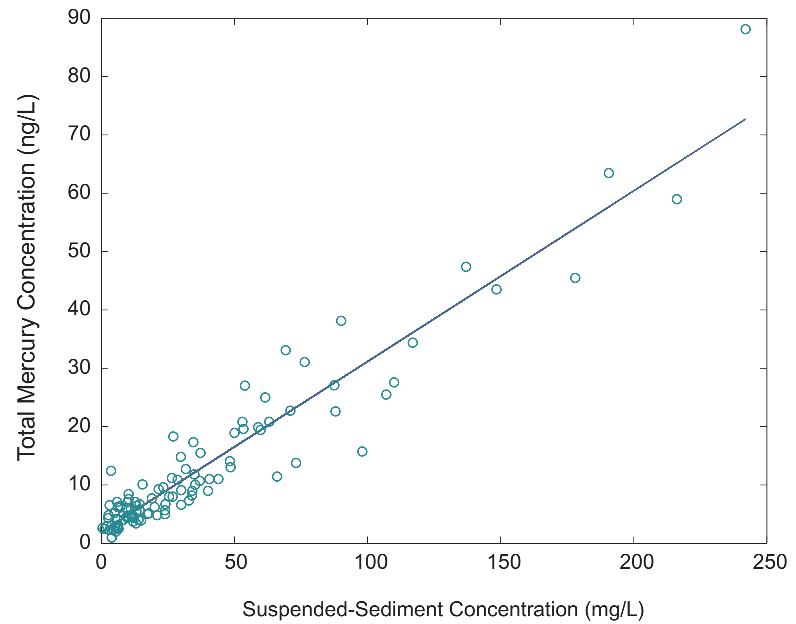


Figure 2. Many priority contaminants are closely associated with sediment particles. This Figure shows the close relationship between mercury and suspended sediment in RMP samples from San Pablo Bay, 1993-2000. Because of this close relationship, suspended sediment monitoring can provide insights into the behavior of mercury in the Estuary.

1993-2000 (Figure 4). The objective was exceeded about 25% of the time.

Compliance with the water quality objective depends on the amount of suspended sediment, which, in turn, depends on the motion of Bay water. Faster water applies more force to the bottom of the Bay, resuspends bottom sediment, increases suspended sediment concentration, and can increase total mercury concentration above the water quality objective. The motions of the earth and moon create tidal cycles and periods of faster water. Semimonthly (spring tides), monthly, semiannual tidal cycles, and the strongest winds in spring and summer that generate the largest waves, account for most of the variability in Figure 4 and determine whether the water quality objective is met (Schoellhamer 2002).

Sediment Transport Explains Contaminant Distribution: Petaluma River

The RMP consistently has measured high concentrations of contaminants in the mouth of the Petaluma River, which drains into northern San Pablo Bay (RMP 2002). Sediment transport between the Petaluma River and San Pablo Bay creates high suspended sediment concentrations, which largely explains the area's high concentrations of contaminants.

The USGS and the University of California at Davis collected continuous hydrodynamic and suspended sediment concentration data in the Petaluma River from January 1999–August 1999, and from September 2000–March 2001 (Barad et al. 2001). These data complemented those from the RMP/USGS continuous suspended sediment concentration station in northwest San Pablo Bay, at Channel Marker 9 (Figure 1) (Ganju et al., written commun., 2003). The geometry and tidal currents in the area create a process of sediment erosion and deposition that repeats with each tidal cycle (about every 12.4 hours). As water flows seaward on ebb tides, the tidal currents apply force to the river bed. An upstream deposit of sediment on the bed of the Petaluma River is eroded and mixed into the water column (Figure 5). As this suspended sediment mass moves downstream, very high suspended sediment concentration are present (>500 mg/L). Once the suspended sediment mass reaches San Pablo Bay, the slack tide and broad area allow sediment to drop out of the water, forming a downstream sediment deposit. As water begins flowing landward immediately after the tide turns from slack to flood, the down-

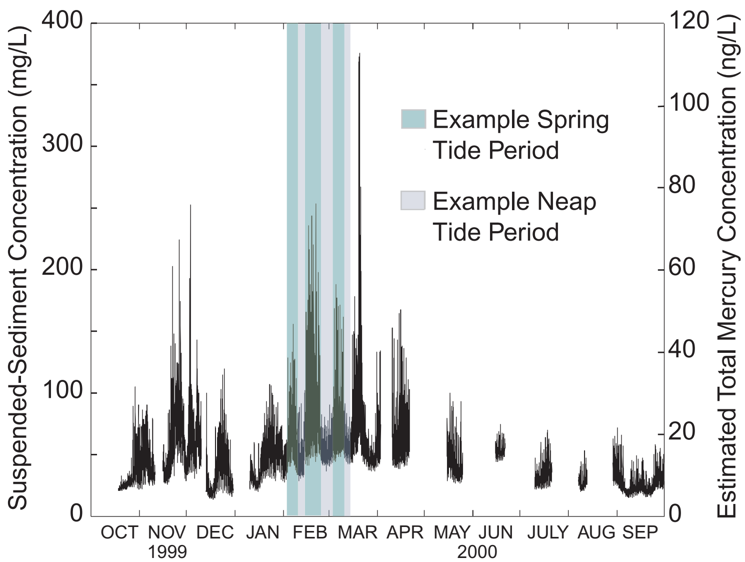


Figure 3. Suspended sediment concentrations in the Bay are highly variable, driven primarily by tides, wind, and freshwater inflow. Suspended sediment concentration (left axis) and estimated total mercury concentration (right axis) at Point San Pablo during water year 2000. Concentrations are highly variable through the year, reflecting physical processes such as the spring-neap and diurnal tidal cycles, rainfall and runoff, and wind-wave resuspension of bottom sediment. The highest concentrations are caused by increased sediment supply during the rainy season (October through April) and resuspension and transport of bottom sediments during energetic spring tides.

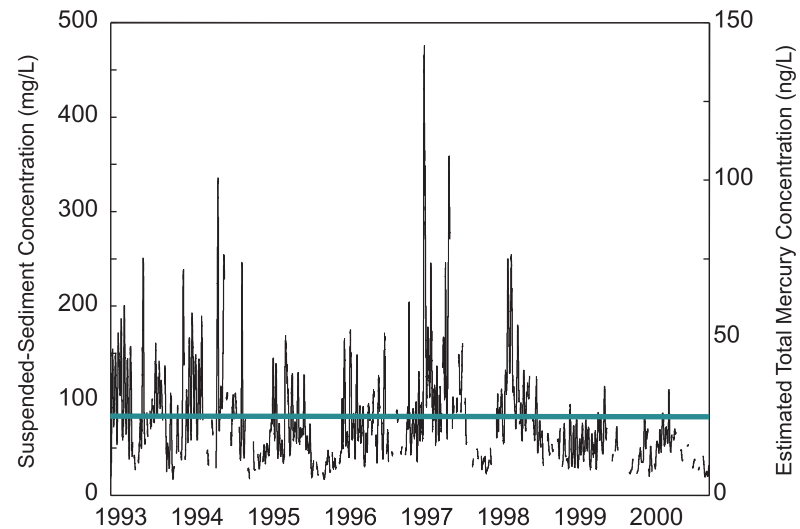
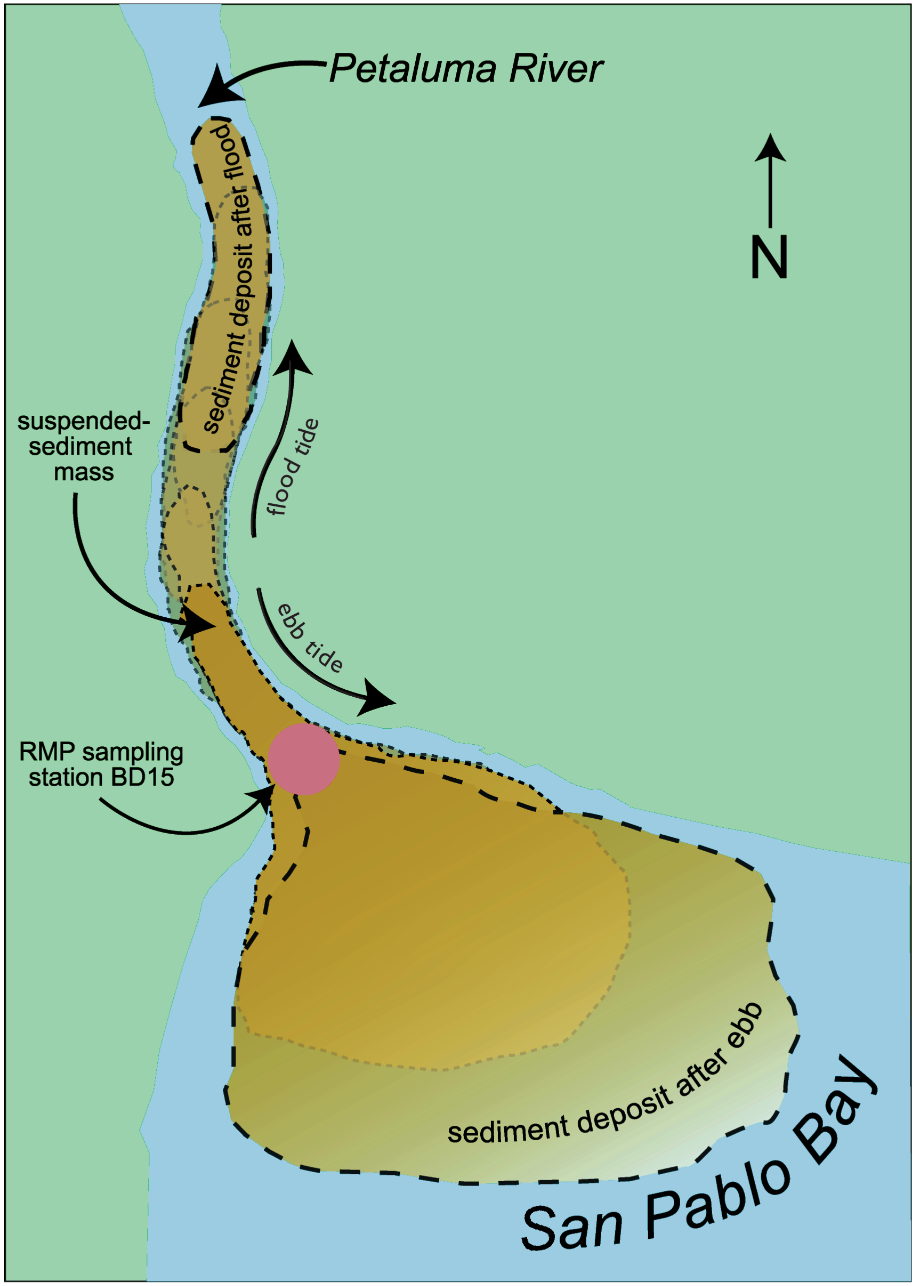


Figure 4. Fluctuations in suspended sediment concentrations drive fluctuations in concentrations of contaminants in Bay water. The water quality objective for mercury concentration is 25 ng/L averaged over any four-day period (horizontal line on graph). This figure shows four-day average suspended sediment and estimated total mercury concentrations at Point San Pablo for direct comparison to the water quality objective. Much of the variation observed can be attributed to the processes described in Figure 3. Another important factor is the trend toward declining sediment loads to the Estuary, especially apparent in the dry years of 1999 and 2000. With less sediment entering the Bay, there was less sediment that could be mobilized by tides and wind, suspended sediment concentrations were lower, and the water quality objective was met during all but the strongest spring tides. Continued declines in sediment load to the Estuary could lead to fewer and fewer exceedances of the mercury water quality objective.

Figure 5. Sediment dynamics explain spatial patterns in contaminant concentrations. The RMP consistently has measured high concentrations of suspended sediment and contaminants in the mouth of the Petaluma River, which drains into northern San Pablo Bay. Sediment transport studies have shown that these high concentrations are due to the oscillation of a cloud of sediment back and forth between San Pablo Bay and the Petaluma River. Sediment deposits at slack tides, and is in motion during flood and ebb tides.



stream sediment deposit is re-suspended and transported upstream. This to and fro process then repeats, with the same sediment mass oscillating back and forth between the Petaluma River and San Pablo Bay. Sediment effectively is trapped within this area, except during large flows in the Petaluma River. This process accounts for the high concentrations of suspended sediment concentration and contaminants in RMP samples collected at the mouth of the Petaluma River. Similar conditions were observed at the mouth of Sonoma Creek.

Sediment and Contaminant Loads from the Central Valley

California's Central Valley historically is the dominant source of runoff and sediment to San Francisco Bay, and it continues to be an important source of contaminants. Hydraulic gold mining in the Sierra Nevada from 1852–1884 utilized and discharged mercury and enhanced the supply of sediment to Central Valley rivers, subsequently causing an increase in sediment and mercury loads from the Valley into the Bay (Figure 6). During the 20th century, watershed runoff delivered contaminants from agricultural and industrial development to the Estuary. For most contaminants, the largest source has been the Central Valley (Davis et al. 1999, 2000). Future population growth is expected to be greater in the Central Valley than in the San Francisco Bay Area, which may increase the Central Valley's importance as a source of contaminants to the Estuary.

In a RMP study, the USGS and SFEI are collaborating to quantify sediment and contaminant loads from the Central Valley to San Francisco Bay. Tides, large channel cross sections, and episodic flood pulses complicate load estimation. McKee et al. (2002) combined USGS continuous suspended sediment concentration data and California Department of Water Resources (DWR) outflow data at Mallard

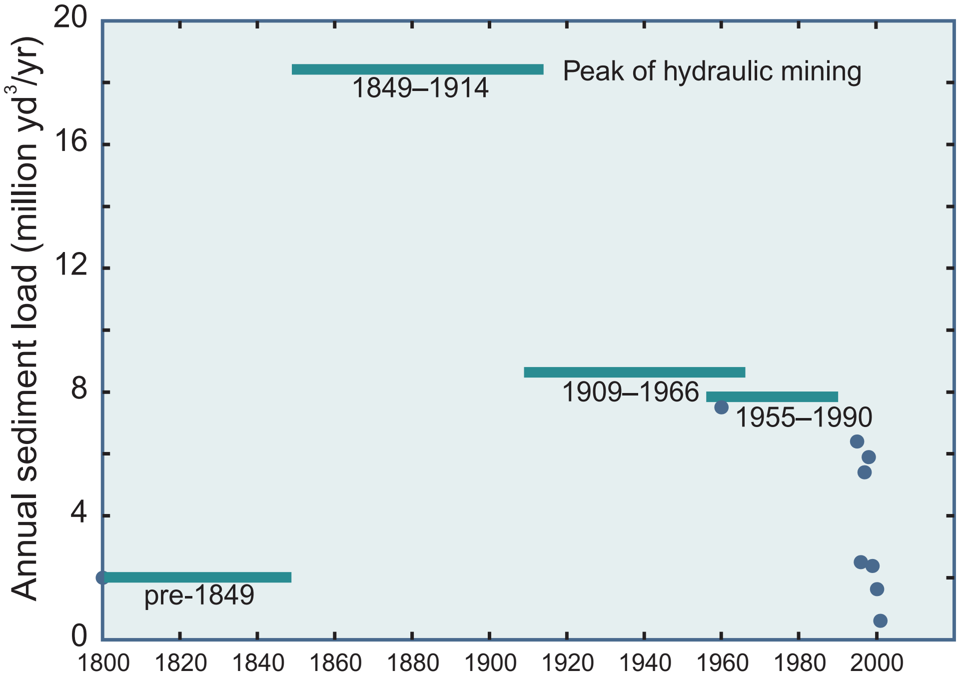


Figure 6. Sediment supply to the Estuary has declined in recent years, making sediment a scarce resource and possibly exacerbating water quality problems. Estimated sediment inputs to the San Francisco Estuary (Gilbert 1917, Krone 1979, Porterfield 1980, Ogden Beeman, and Associates 1992, McKee et al. 2002). Bars indicate estimates over entire period and points indicate yearly estimates. Hydraulic gold mining in the Sierra Nevada in the late 1800s greatly increased sediment loads over pre-1849 levels. Loads declined in the 1900s due primarily to the establishment of reservoirs on tributaries throughout the Estuary watershed. At present, the diminishing supply of sediment threatens to exacerbate existing water quality problems by increasing erosion of sediment from the Bay floor.

Island to estimate sediment loads into the Bay. They determined an average load of 5.2 ± 0.9 million yd^3 per year from 1995 to 1998. Additional sediment data have been collected since 1998 (Buchanan and Ruhl 2001, Buchanan and Ganju 2002). Using the same methods as described by McKee et al. (2002), the estimated average annual sediment load from 1995-2001 (7 years) was 3.6 ± 0.6 million yd^3 per year, down from the hydraulic mining peak of 18.4 million yd^3 per year between 1849-1914 (Gilbert 1917). This decrease in sediment load (Figure 6) is consistent with decreasing sediment load from 1957-2001 in the lower Sacramento River (Wright and Schoellhamer 2003). In a followup to the McKee et al. (2002) study, the RMP is characterizing contamination of suspended sediment entering the Bay to develop improved estimates of contaminant loads from the Central Valley.

Sediment load affects water quality in the Bay. The smaller sediment load from the Central Valley in 1999 and 2000 (Figure 6) probably explains the smaller suspended sediment concentration and increased compliance with the mercury water quality objective at Point San Pablo (Figure 4). With less sediment entering the Bay, there was less sediment that could be mobilized by tides and wind, suspended sediment concentration was less, and the water quality objective was met during all but the strongest spring tides.

It is difficult to predict the long-term effect of reduced sediment load on Bay contamination. On one hand, reduced sediment load from the Central Valley can be expected to reduce concentrations of mercury suspended in water. On the other hand, however, another expected effect of reduced sediment load to the Bay is increased erosion of bed sediment on a regional scale (Jaffe et al. 1999). Erosion of buried sediment, which was deposited in past decades with higher contaminant loads, reintroduces relatively contaminated sediments into circulation in the Bay (Marvin-DiPasquale et al. 2003).

Sediment and Contaminant Budgets

The bed sediment in San Francisco Bay is a major repository and source of many contaminants. For example, PCBs are legacy contaminants that no longer are manufactured but persist in the bed sediment and pose a human health risk because of their accumulation in Bay sport fish. The USGS and RMP are developing a sediment budget and a numerical model to better understand the long-term (decadal) sedimentation of the Bay and associated contaminant fate. These tools will provide an essential foundation for predicting long-term trends in concentrations of persistent contaminants, thus helping improve the development of TMDLs for the Bay.

A financial budget is useful for evaluating income, expenses, and gain or loss of savings. Similarly, a sediment budget is useful for evaluating sediment sources, sediment sinks, and erosion or deposition in the Bay. For contaminants associated with sediment,

Mercury (Hg)

Mercury is naturally abundant in the rocks of the Coast Range of northern and central California. Human activities over the past 150 years have moved a substantial amount of this mercury out of the rocks and into the ecosystem.

Mercury has numerous commercial and industrial uses, including thermometers, fluorescent lamps, dental fillings, and batteries. During the late 1800s and early 1900s, mercury was mined intensively in the California Coast Range for use primarily in gold extraction in the Sierra Nevada. Although the extraction of gold by mercury amalgamation has been banned in the United States, San Francisco Bay continues to receive mercury from mine drainage and mining debris deposits in upland watersheds (SFEI 1999a).

Mercury is found in several forms, some of which have much greater potential for harm than others. Methylmercury (CH_3Hg+) is the form of greatest concern since it accumulates in animal tissue and moves from prey to predator up the food web. Methylmercury is produced by bacterial action in sediment.

Mercury is of high concern with regard to human health since it accumulates in tissues, and its levels increase up the food web. Human exposure to mercury occurs primarily through consumption of contaminated fish. Mercury is a neurotoxicant and is particularly hazardous to the developing nervous system of fetuses and children.

Mercury also has potential to harm the ecosystem, especially birds and other wildlife high in the food web.

development of a sediment budget is needed to develop a contaminant budget. The most recently published sediment budget for San Francisco Bay was written by Ogden Beeman and Associates (1992). Sediment supply and dredging volumes have decreased since, and large wetland restoration projects and airport runway expansion projects that would create new sediment sinks have been proposed. The USGS is using new suspended sediment concentration data, interpretive studies, and numerical models to update the sediment budget for San Francisco Bay.

A simple numerical model can be used to provide a sediment or contaminant budget that varies over decades. Davis (2003) developed a numerical model of the long-term fate of PCBs in San Francisco Bay that represented the Bay as one well-mixed box. A one box model, however, blurs over the different long term deposition and erosion patterns known to exist in different parts of the Bay (Jaffe et al. 1999). The USGS is collaborating with SFEI to develop a multi-box model for PCB cycling in San Francisco Bay. The wealth of suspended sediment concentration and bathymetric data available in San Francisco Bay will be used to improve the reliability of the model.

Science to Better Manage the Bay

The data and findings from the RMP and USGS sedimentation studies not only benefit the RMP but also benefit restoration projects, construction projects, such as the proposed San Francisco Airport runway expansion, and other scientific studies. Data from these studies are published (Buchanan and Ganju 2002) and available on the internet <http://sfports.wr.usgs.gov/Fixed_sta/>, and significant findings are published in peer-reviewed journals (see the bibliography at <http://ca.water.usgs.gov/abstract/sfbay/sfbaycontbib.html>).

RMP and USGS sedimentation studies provide scientific and programmatic integration that benefit Bay science and management. Sedimentation studies integrate the scientific disciplines of physics, chemistry, and ecology because sedimentation is controlled by physics and affects the chemistry and ecology of the Bay. The collaboration of the USGS and RMP strengthens both organizations and improves the greater understanding of the Bay. The RMP also benefits from the contributions from other agencies and programs to Bay sedimentation studies. In addition to RMP support received from the San Francisco District of the U.S. Army Corps of Engineers, support for the data and analyses presented in this article came from the California Department of Fish and Game, California Department of Transportation, California Coastal Conservancy, CALFED Bay/Delta Program, San Francisco Bay Regional Water Quality Control Board, U.S. Environmental Protection Agency CISNet Program, U.S. Fish and Wildlife Service Coastal Program, and USGS Place-based and Federal/State Cooperative Programs. In addition, the Interagency Ecological Program supports continuous salinity monitoring stations that are co-located with some RMP sediment monitoring stations, thus reducing the costs to both Programs.

For several reasons, appreciation of the importance of sediment dynamics in the Bay has grown markedly in recent years. First, as discussed in this article, the long-term data set is beginning to yield valuable insights, such as the effect of reduced sediment supply on compliance with water quality objectives. Second, sediment dynamics explains the spatial and temporal variability of some contaminants, such as mercury and PCBs. Third, the development of mass budgets and predictive models has enhanced our understanding of the influence of sediment dynamics on long-term trends in contaminant concentrations. Fourth, massive development and restoration projects (the San Francisco airport extension, CALFED restoration projects, restoration of the South Bay salt ponds) that could have a huge effect on the Bay's sediment budget currently are being evaluated. Continued monitoring and analysis of sediment dynamics is essential to understanding the effects of management actions on water quality and the ecology of San Francisco Bay.

Ten Years of Testing for the Effects of Estuary Contamination

Brian Anderson (anderson@ucdavis.edu) – U.C. Davis, Davis, CA • Scott Ogle – Pacific EcoRisk, Martinez, CA
Sarah Lowe – San Francisco Estuary Institute, Oakland, CA

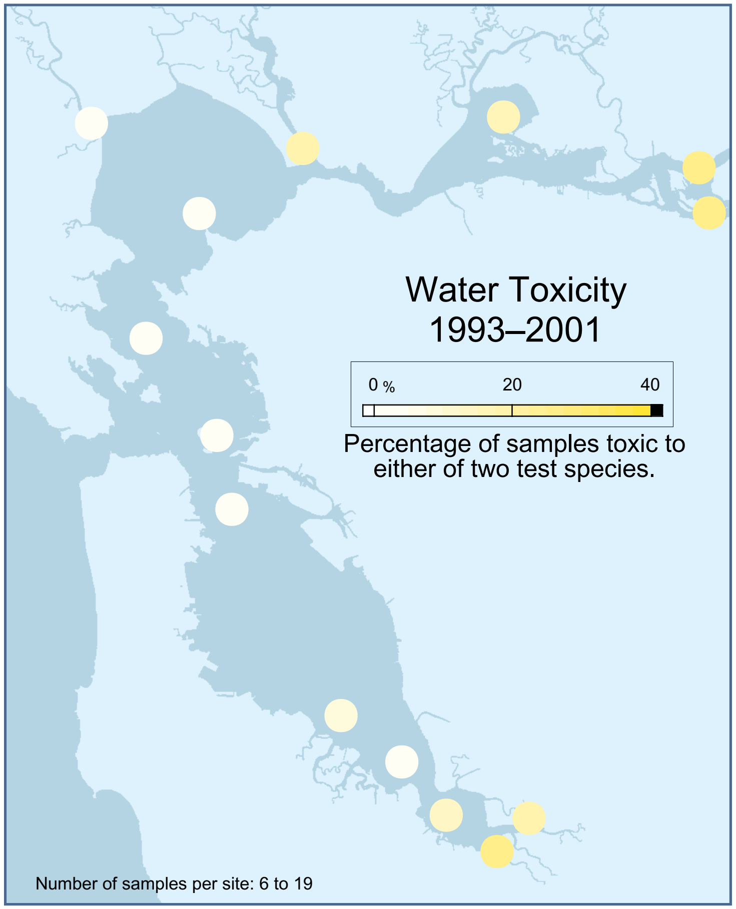


Figure 1. Toxic water in the Estuary has been observed less frequently in recent years. From 1993 to 2001, 13% of water toxicity samples collected by the RMP Status and Trends component were toxic to one or more test organisms in the laboratory (mysid shrimp or bivalve larvae). Most of this toxicity was observed in wet season samples and occurred in the northern and southern reaches of the Estuary. From 1998, only two sites in the southern sloughs of the Estuary have been toxic.

INTRODUCTION

Complex mixtures of contaminants are found in the Estuary and their effects on aquatic life are difficult to evaluate. Knowing the individual concentrations of chemicals is not enough to determine if estuarine waters will be harmful to resident species. Toxicity tests are laboratory procedures designed to determine whether chemical levels in water or sediment samples from the Estuary might impact aquatic life. Water quality objectives adopted by the Regional Water Quality Control Board are established to comply with Clean Water Act provisions that prohibit the presence of contaminants in toxic amounts (Basin Plan, 1995). Toxicity tests are used to monitor compliance with these objectives. Combined with chemical measurements (in water, sediment, and tissue), biological community characterizations, measures of other factors that may affect aquatic organisms, and studies of effects on populations of aquatic organisms, laboratory toxicity tests add to the group of measurements used to assess the health of the estuarine ecosystem.

Toxicity testing has been included in the RMP since the Program began in 1993. This element of the RMP has been continually adjusted and improved providing an excellent example of adaptive program management. This element appears to have documented the reduction of aquatic toxicity in the Estuary in response to declining use of organophosphate (OP) pesticides.

Contaminants enter the Estuary through a number of pathways, and can be dissolved in water or bound to sediment particles. Water and sediment toxicity are tested separately: water toxicity testing monitors possible effects of chemicals on organisms that live in the water column, and sediment toxicity testing assesses possible impacts on the Estuary's benthos (sediment dwellers). For the RMP, water toxicity is monitored using mysid shrimp and larval fish. Mysid shrimp represent a class of organisms that are important food for fish in the Estuary, and the species being used by the RMP is among the most sensitive test species for water, especially to pesticides and petroleum-related contaminants. Toxicity of sediment contaminants is monitored using mussel embryos and shrimp-like organisms called amphipods. Both tests are considered sensitive indicators of benthic community health.

Aquatic Toxicity in the Estuary

Since 1993, 13% of the water toxicity samples tested by the Status and Trends component of the RMP were found to be toxic to at least one test species. Most of those occurrences happened between 1995 and 1997 in the northern and southern reaches of the Estuary (Figure 1) during the wet season. Since 1998, only two southern slough sites (C-3-0 and C-1-3) showed toxicity (four out of sixteen samples from those sites).

This wet season aquatic toxicity observed in the northern and southern Estuary is suggestive of adverse effects on aquatic invertebrates and the estuarine food web. Long-term studies have reported declines in zooplankton abundance in the Estuary, with recent zooplankton densities from one-tenth to one one-hundredth of those in the early 1970s (Obrebski et al. 1992). While there are other factors that may be driving the zooplankton decline, such as the introduction of the Asiatic clam *Potamocorbula amurensis* (a highly efficient filter feeder) in 1986 (Thompson 1999; Lucas et al. 1999; Parchaso and Thompson 2002), water diversions upstream, and altered food web predation patterns, the use of pesticides has increased substantially over this same period of time, suggesting that contaminants may be contributing to the zooplankton declines (see *Changes in Pesticide Use* below).

Based upon the wet season toxicity observed in the Status and Trends monitoring, the RMP initiated a Pilot Study in the winter of 1996 to test the hypothesis that stormwater runoff and other surface water runoff events were the primary sources of episodic water toxicity in the Estuary. The Pilot Study sampled stormwater runoff events at Mallard Island (near the confluence of the Sacramento and San Joaquin Rivers), and in several smaller tributaries throughout the Estuary (see Figure 2).

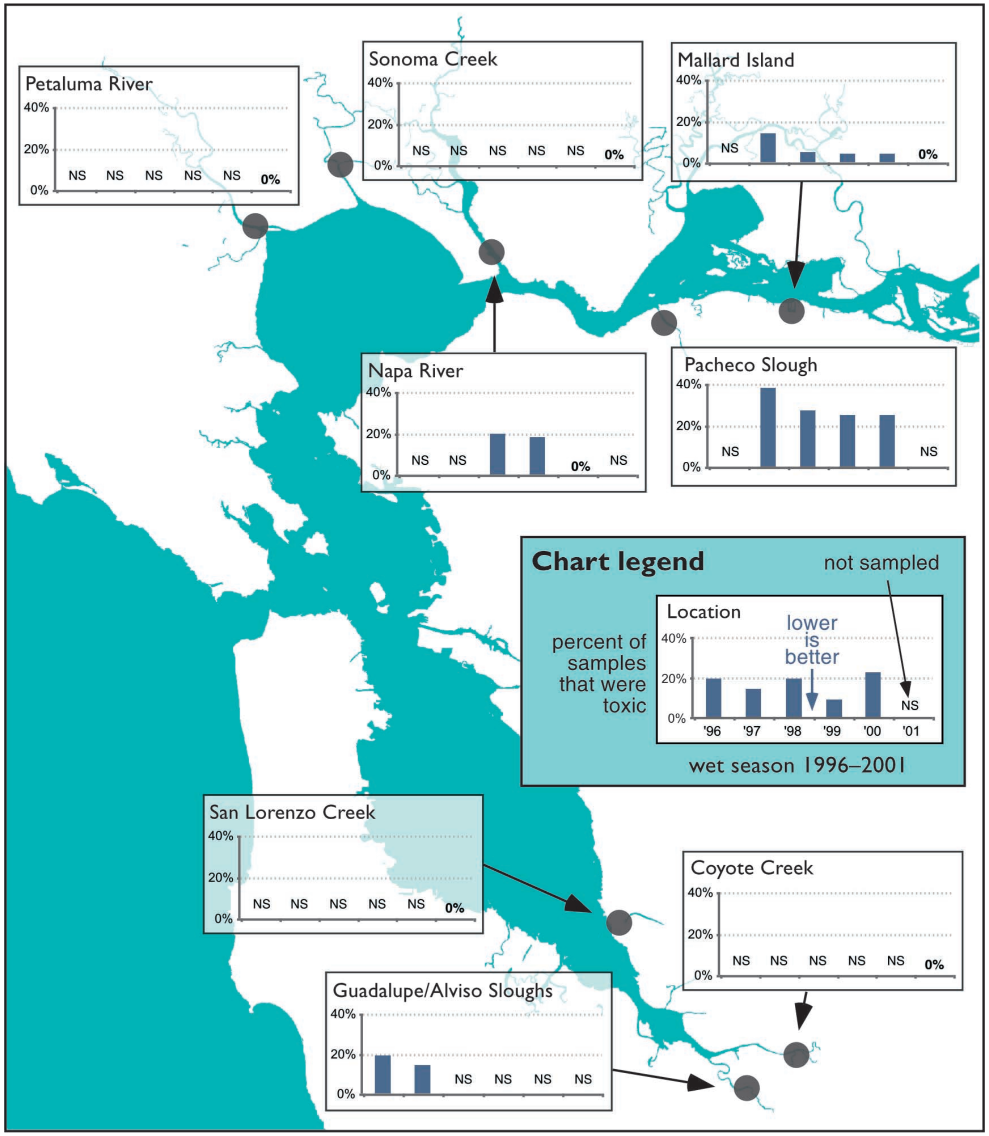


Figure 2. Toxic water samples from Estuary tributaries have also been observed less frequently in recent years. The RMP's Episodic Aquatic Toxicity Study has been sampling toxicity to mysid shrimp and larval fish in tributaries around the Estuary since 1996. During this period, the frequency of observed aquatic toxicity in the tributaries has been decreasing, possibly as a result of a shift in the kinds of pesticides used in the surrounding watersheds.

Is the Water Toxic in the Tributaries?

While most of the water samples tested by the RMP in the Estuary have not been toxic, stormwater samples collected from tributaries and in the northern Estuary following significant rainfall events in 1996 and 1997 were toxic (Figure 2). During two periods in 1998, three consecutive samples taken at two to three day intervals in the northern Estuary were all toxic, suggesting that extended periods of toxicity may occur. Studies on the Sacramento and San Joaquin rivers during this time period found that water in some sections of those rivers were frequently toxic, and OP pesticides (e.g., diazinon and chlorpyrifos) were believed to have been responsible for much of the toxicity (Foe 1995, Ogle et al. 1998). Other studies found that many samples of stormwater runoff from urbanized creeks in the Estuary were also toxic (S.R. Hansen and Associates 1995, Katznelson and Mumley 1997).

In recent years, the frequency of observed wet season aquatic toxicity has declined, and has coincided with the reduction in use of OP pesticides. In 2000, the U.S. EPA acted to reduce the use of two key OP pesticides, chlorpyrifos and diazinon, by phasing out their use in home and garden applications and restricting their use in agriculture. Local agencies around the Estuary are also engaged in public information efforts to reduce the use and improper disposal of OP pesticides by homeowners and businesses. Meanwhile, the urban and agricultural pesticide markets are turning to various alternatives to diazinon and chlorpyrifos, such as pyrethroid insecticides (see sidebar, page 31).

Stormwater toxicity monitoring continues to be conducted by the RMP. Recently, the frequency of toxicity has decreased, most notably at Mallard Island, where none of the 53 samples collected during the wet season of 2001–2002 were toxic (Figure 2). There has also been a marked decrease in the magnitude of the toxicity. Many of the toxic samples collected in the first three years of the Pilot Study caused >50% mortality of test organisms, with several causing 100% mortality. Of the wet season 1999-2000 samples collected, only one resulted in >50% mortality, and none of the samples collected in 2000-2001 resulted in >25% mortality.

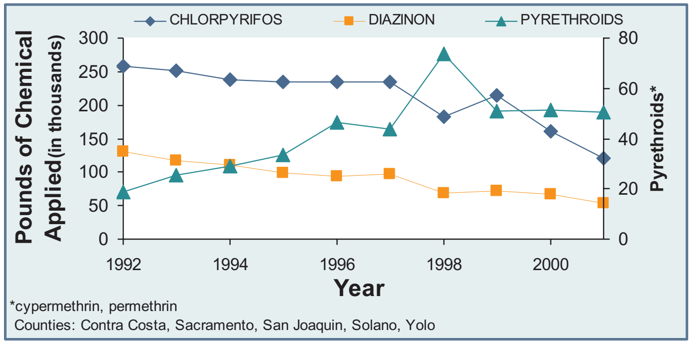


Figure 3. Recent changes in pesticide use may account for the observed decrease in aquatic toxicity in local tributaries of the Estuary. With regulatory measures (in 2000) to reduce the use of OP pesticides such as chlorpyrifos and diazinon in agriculture and homes and gardens, the use of pyrethroid insecticides is expected to increase. This graph shows the pounds of pesticides (in thousands of pounds) applied annually in nearby counties, 1992 – 1998.

Data source: CA Department of Pesticide Regulation http://calpip.cdpr.ca.gov/cfdocs/calpip/prod/main.cfm

Changes in Pesticide Use

Apparent reductions in the magnitude and frequency of ambient water toxicity to the mysid shrimp over the past several years has coincided with recent reductions in the application of OP pesticides in the Estuary's watersheds (Figure 3). While reduced OP applications appear to have remedied the mysid toxicity problem in the Estuary, other pesticides that may pose

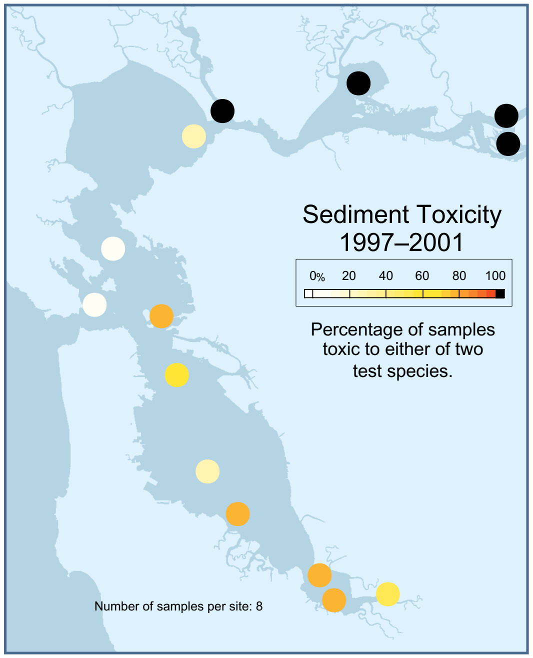


Figure 4. The frequent occurrence of toxic sediment samples in the Estuary is a major concern. From 1997 to 2001, 63% of sediment toxicity samples collected by the RMP Status and Trends component were toxic to one or more test organisms in the laboratory. Sediment toxicity is persistent in the Estuary and more frequent in the northern and southern reaches and near the mouths of small tributaries.

Toxicity Testing

Using contaminant concentrations to predict harm to estuarine life is difficult, as a contaminant's potential for harm is affected by its context in the estuarine environment. Other contaminant levels, salinity, temperature, and many other variables may influence a contaminant's effect.

A more direct approach to assessing potential harm, which avoids many of the difficulties of interpreting contaminant concentrations, is to expose organisms (such as mussels or shrimp) to Estuary water or sediment in the laboratory and look for adverse effects such as developmental abnormalities or death. If a clear adverse effect is seen, it is considered an indication that harm is occurring in the Estuary itself. The ecological relevance of laboratory tests is a matter of some debate, as some of the species used in RMP tests do not actually reside in the Estuary. The RMP is considering increasing its use of resident species to address this issue.

Toxicity tests give no indication of what in the sample is responsible for the observed toxicity. Additional tests, known as toxicity identification evaluations (TIEs) attempt to identify the toxic agent(s). In TIEs, toxic samples are treated to remove a particular type of chemical, and toxicity tests are rerun to see if the toxicity has been eliminated. In this way, indirect identifications can be made. When contaminant mixtures are present, conclusive identification of what is causing the toxicity is often not possible. The RMP plans to increase the use of TIEs on water and sediment samples.

For information on the specific toxicity tests used by the RMP, see the RMP Annual Monitoring Summary reports at <www.sfei.org>.

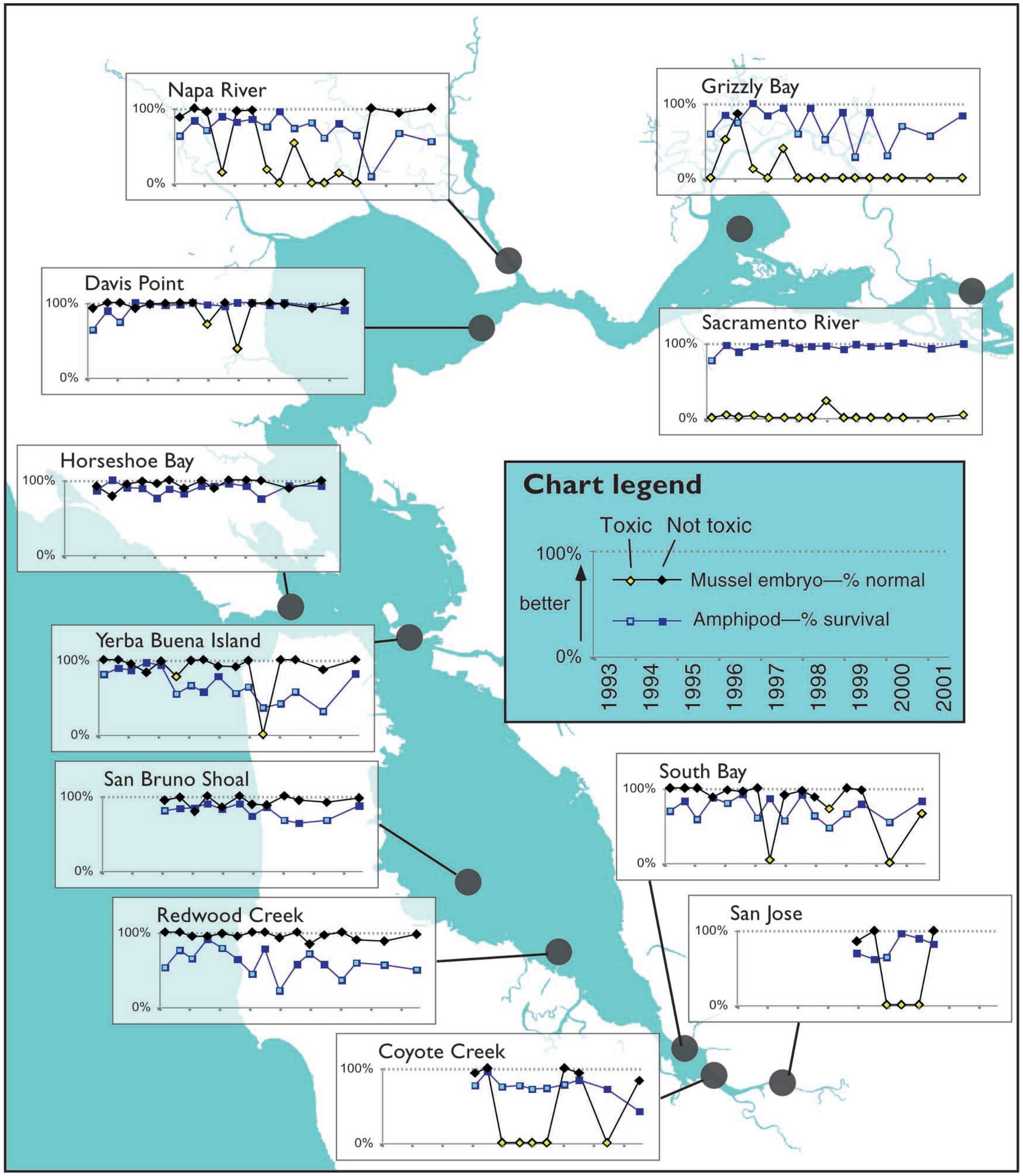


Figure 5. Sediment toxicity in the Estuary is persistent, shows seasonal and regional patterns, and is manifested differently in two laboratory test species. There is more frequent toxicity during the wet season than the dry season, particularly to amphipods. The mussels tend to have a pronounced all-or-nothing response. Samples are persistently toxic to mussels at the Rivers stations and periodically at the South Bay stations.

new problems are being substituted for OP pesticides. For example, the use of alternatives such as pyrethroid insecticides (see sidebar, page 31) has increased over the past few years. Pyrethroids have different properties than OP pesticides, with a greater tendency to adsorb to sediment and greater toxicity to fish. Therefore corresponding changes in the toxicity monitoring approach may be needed (i.e., using tests and test species that will be more sensitive to changing use patterns of pesticides and their fate and transport characteristics). It is critical that the RMP remains vigilant of changes in pesticide use within the Estuary's watersheds and continues to adapt the monitoring approach in response to those changes.

Sediment Toxicity

Toxic sediment is found regularly at a number of sites throughout the Estuary. During the last five years, 63% of the sediment samples tested were toxic to at least one test organism (Figure 4). Since 1993, the RMP has seasonally evaluated the toxicity of sediments to mussel embryos and amphipods. For each seasonal sampling period since 1993, the proportion of sediment samples that were toxic to at least one test organism ranged from 33% to 100%, with no clear overall trend, but with clear seasonal differences (see Figure 5).

As with water toxicity, sediment toxicity is more frequent in the Estuary during the wet season than in the dry season, suggesting stormwater is an important source of contamination that may cause sediment toxicity. This pattern is particularly clear for amphipods. For example, 51% percent of the winter samples tested between 1993 and 1999 were toxic to amphipods, while only 16% of the summer samples were toxic during this period. [Since 2000, the RMP has shifted to dry season toxicity monitoring as part of the redesign of the Status and Trends component of the RMP (*RMP News, Vol 6:2*).]

Sediment from certain stations in the Estuary has been consistently toxic to amphipods and mussel embryos (Figure 5). Samples from Grizzly Bay, the mouth of the Napa River, Redwood Creek, and the

South Bay have usually been toxic to amphipods. Samples from these and other stations have also been toxic to mussel embryos. All samples collected in the northern Estuary (Grizzly Bay and the Sacramento and San Joaquin Rivers) have been toxic to mussels since 1994.

As suggested before, the magnitude of toxicity (the number of dead or poorly developed animals) has been greater in samples collected during the winter months. Analyses to identify the cause of the sediment toxicity have yielded a variety of answers, probably in part due to the complex mixtures of chemicals involved. Comparisons of the chemical data to toxicity test data indicated that amphipod mortality correlated with mixtures of chemicals in sediments, as well as to specific metals and pesticides (Thompson et al. 1999; Anderson et al. 2000; Phillips et al. 2000). Causes of toxicity to mussel embryos were less apparent.

Causes of sediment toxicity have been further investigated using toxicity identification evaluations (TIEs). TIEs are laboratory procedures designed to first characterize the class of chemicals causing toxicity, then identify and confirm specific chemicals responsible for toxicity. TIE procedures developed by the U.S. EPA and novel techniques developed as part of RMP special studies have shown that copper was the likely cause of inhibited bivalve embryo development in sediment samples from the Grizzly Bay station (Phillips et al., in press). TIEs have indicated that sediment-associated metals are also the cause of toxicity in samples from a southern Estuary station, though the specific metals responsible have not been identified. TIEs with amphipods have shown that the persistent toxicity observed in Grizzly Bay sediment is not likely due to organic chemicals (such as pesticides), but instead is caused by some acid-soluble contaminant, such as a metal (Anderson et al. 2000).

Monitoring information can also suggest possible solutions to toxicity problems. For example, many of these RMP stations are near urban creeks and rivers that receive seasonal stormwater runoff. By identifying the specific chemicals responsible for observed toxicity, resource managers may be able to implement studies to confirm whether urban runoff is an important source of these contaminants. Once this is confirmed, programs may be designed to reduce inputs of these chemicals to the Estuary. As a first step, a RMP special study has been proposed to monitor sediment toxicity and chemistry at the base of selected creeks and rivers during the rainy season to assess what role these sources play in contributing toxic sediments to the ecosystem.

Looking to the Future

Sediment toxicity is likely to persist for many years to come, considering the continuing toxicity observed in the RMP. Additional special studies are planned to further examine whether water and sediment toxicity tests used in the RMP are accurate predictors of impacts on the Estuary's aquatic and benthic communities. Because the amphipod (*Eohaustorius estuarius*) used in the RMP is not a resident of the Estuary, there has been some debate regarding its ecological relevance. Sensitivity of selected resident organisms to key chemicals of concern will be compared to sensitivity of this amphipod species. Similar tests are planned to evaluate the water test species. Information from these experiments will confirm whether the current species employed are adequately sensitive to represent and ensure the protection of the Estuary ecosystem.

From a Regional Board perspective, RMP toxicity monitoring has played a crucial role in tracking possible effects of contaminants in the water and sediment of San Francisco Bay and its major tributaries. Documentation of the toxicity associated with OP pesticides played an important role in the EPA's reevaluation of these pesticides. The subsequent measurement of decreasing aquatic toxicity with the coinciding decrease in OP pesticide use appears to demonstrate the success of management actions. However, since new classes of pesticides are being increasingly used to replace OP pesticides (such as pyrethroids that partition in the sediment and have higher toxicity in fish), new approaches to monitoring potential effects are needed. Continued monitoring of toxicity with associated chemical measurements, the development of TIE procedures for emerging pesticides, and the increased use of TIEs will allow us to keep current on the status of toxicity in the Estuary and its tributaries, help determine the causes of toxicity, and inform regulatory decisions.

Pyrethroid Insecticides

The implementation of U.S. EPA restrictions on the use of organophosphate (OP) insecticides has prompted pesticide manufacturers to turn to using alternatives insecticides to meet market demands. Pesticide use data (see Figure on page29) indicate that pyrethroid insecticides are one of the primary replacements of OP pesticides.

Pyrethroids are synthetic analogs of pyrethrins, a class of naturally occurring pesticides with insecticidal properties that are found in the flower heads of chrysanthemums. Pyrethrins have been harvested from chrysanthemums and used as a natural insecticide since the early 1900s. More recently, chemists modified the structure of pyrethrins to make them more chemically stable and more toxic than naturally occurring pyrethrins.

Common pyrethroids include permethrin, cypermethrin, esfenvalerate, bifenthrin, cyfluthrin, and deltamethrin, among others. They have been used as active ingredients in residential lawn and garden retail products (e.g., Ortho, Scotts, Bayer Advanced, Spectracide, and Real-Kill). Pyrethroids interfere with the function of the nervous system and very effectively block nerve impulse transmission in insects. Humans can rapidly metabolize and eliminate pyrethroids, so they appear to pose low risk to human health. However, fish and aquatic arthropods are quite sensitive to pyrethroids, raising concern for possible non-target impacts on aquatic environments due to agricultural, structural, and landscape maintenance applications.

Pyrethroids behave differently in the environment than organophosphate insecticides, with greater persistence and a stronger tendency to bind to sediment particles than organophosphates. The RMP is adjusting its toxicity monitoring to better evaluate compounds with these chemical and toxicological properties.

Ten Years of Pilot and Special Studies:
Keys to the Success of the RMP

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PILOT STUDY

A monitoring study conducted on a trial basis in order to determine whether it is suitable for inclusion in RMP status and trends monitoring.

SPECIAL STUDY

A study that helps improve monitoring measurements or the interpretation of monitoring data or that serves to meet RMP objectives through activities other than monitoring.

It is widely acknowledged that the RMP has generated a world-class body of science describing contamination in San Francisco Bay, and this is an obvious sign of the success of the Program. Less obvious, but equally important to the continuing support enjoyed by the RMP, are the processes that have been established to facilitate collaboration and communication among RMP participants and to ensure efficient use of funds to answer the most pressing management questions. Stable funding has allowed the RMP to develop an efficient organizational structure and processes that enable the Program to adapt to changing management priorities and advances in scientific understanding. The RMP in 2003 looks very different from the RMP in 1993. Pilot and special studies are one of the main mechanisms that have allowed this growth and improvement.

The Maturation of a Monitoring Program

In its infancy in 1993, the RMP was a $1.2 million program narrowly focused on measuring spatial and temporal trends in contaminant concentrations and toxicity in the main channel of the Estuary. In 2003 the RMP has matured into a multifaceted $3.4 million program of study that evaluates spatial and temporal trends in chemical contamination and toxicity in a more comprehensive manner, and also assesses contaminant effects, contaminant loading, and performs broad-scale synthesis of information from RMP and other programs. Pilot and special studies in the RMP have allowed the Program to adapt in response to changes in the regulatory landscape, advances in understanding of the Estuary, and a continual drive to adjust the Program to better meet its objectives.

RMP pilot and special studies have been keys to both the adaptive management of status and trends monitoring and the success of the RMP in meeting its objectives related to effects, loading, and synthesis (see RMP objectives on page 34). Adaptive management is achieved through several mechanisms in the RMP. One of these is an institutional structure with committees and workgroups (Figure 1) that meet quarterly to track progress and plan future work. This structure allows for continual adjustment of the Program. Another important mechanism by which the Program adapts is periodic Program Reviews, where independent, prominent experts in environmental monitoring evaluate the Program as a whole. Program Reviews are conducted on approximately a five-year cycle, with the most recent one occurring in 2003. Pilot and special studies are the third major mechanism by which the Program adapts. These studies constitute a mechanism for responding quickly to new information or concerns, assessing new technical approaches, investigating particular questions that have defined endpoints, and evaluating new directions for status and trends monitoring.

Pilot and special studies have been included in the RMP every year, and have lead to significant additions and refinements to status and trends monitoring. Pilot and special studies currently account for 16% of the annual budget (Figure 2). The major elements added to Status and Trends monitoring in the past 10 years that originated from pilot studies include hydrography and phytoplankton, suspended sediment dynamics, and fish contamination.

Some of the refinements resulting from special studies include ongoing development of mass budget models, an updated list of target chemicals for monitoring, an optimized bivalve monitoring program, and incorporation of surveillance monitoring and interlaboratory quality assurance exercises.

Got Ideas?

Given the importance of pilot and special studies to the success of the Program, it is essential to have an effective process for generating new study ideas and deciding which studies to fund. One of the main products of the first Program Review was a Pilot and Special Study Selection Procedure (PSSSP). The PSSSP clearly lays out the responsibilities of the parties involved in the decision-making process: the Steering Committee, Technical Review Committee (TRC), Regional Board, and SFEI. The PSSSP also lays out the steps that begin with the generation of ideas and culminate in the implementation of a well-planned study.

One of the valuable features of the procedure is that it establishes a wide funnel to channel potentially useful ideas into the process. Many ideas originate from within the committees and workgroups of the Program. However, input from scientists from outside the Program is also encouraged. These outside scientists may also end up implementing the proposed work, providing a means of broadening the scientific horizons and skills of all parties to the RMP. Ideas for new studies are solicited on the RMP web site <www.sfei.org/rmp/>.

In December of each year, the annual cycle for considering these studies begins. A list of ideas compiled through the year is evaluated by the TRC. Depending on the amount of funding available that year, a few ideas are selected for further elaboration and consideration. More detailed conceptual scopes of work are then prepared on these topics and reviewed by the TRC. In June of each year, the TRC establishes the relative priority of all of the pilot and special study concepts based on their technical merit. In July, the Steering Committee then decides which studies can be included in the next year's program. Studies that would require an increase in the overall budget of the Program have a longer planning horizon, given the minimum one year lead time needed to obtain Steering Committee approval and implement this sort of increase.

Continued on page 34

Table 1. RMP Pilot and Special Studies from 1993–2005. A large number of pilot and special studies have been conducted in the RMP. Some of the studies have become annual features of the Program as indicated in the Tables, and some have not. All of the studies, however, have yielded valuable information.

Pilot Studies

Hydrography and phytoplankton	93	I											
Suspended sediment dynamics	93	I											
Benthic macrofaunal assemblages		94	95	96	97	98							
Wetlands monitoring			95	96									
Estuary interface				96	97	98	99	00	01				
Fish contamination					97			00			I		
Episodic toxicity						98	99	00	I				
Atmospheric deposition						98	99	00	01				
Mercury deposition network									01	02	03	04	
Exposure and effects									01	02	03	04	05

Years active
I = year incorporated into RMP

Special Studies

Comparison of local effects monitoring and the RMP		94											
Optimal water quality sampling strategy		94											
Development of a chronic Ampelisca abdita bioassay		94	95										
Methods for analysis of spatial and temporal patterns (trace elements)			95										
Workshop on ecological indicators			95										
Interlaboratory comparison exercises			95										
Sediment contamination indicators				96									
Review of bivalve monitoring				96									
Sediment information synthesis						98							
Sources, pathways, and loadings literature reviews						98	99	00	01	02	I		
Mass budget models									01				
Contaminant transfer from sediment to biota									01				
Surveillance monitoring									01	02			
CTR monitoring										02	03		
Loads from rivers										02	03	04	
10 year synthesis											03	04	

RMP Objectives

- Describe patterns and trends in contaminant concentration and distribution
- Describe general sources and loading of contamination to the Estuary
- Measure contaminant effects on selected parts of the Estuary ecosystem
- Compare monitoring information to relevant water quality objectives and other guidelines
- Synthesize and distribute information from a range of sources to present a more complete picture of the sources, distribution, fates, and effects of contaminants in the Estuary ecosystem

Pilot and Special Study Highlights, 1993-2003

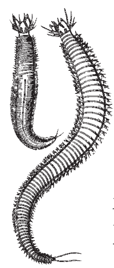
A large number of pilot and special studies have been conducted in the RMP since 1993 (Table 1, previous page). Some of the studies have become annual features of the Program, and some have not. All of the studies, however, have yielded valuable information. Highlights of the major studies are described below. Technical reports are available at <www.sfei.org>.

Hydrography and Phytoplankton and Suspended Sediment Dynamics.

See articles by Cloern et al. and Schoellhamer et al. in this issue.

Benthic Pilot

Benthic organisms are known to be sensitive to sediment contamination, and benthic community monitoring is used in all large state and federal monitoring programs. Looking towards including a biological effects component in the RMP, the Benthic Pilot Study was conducted from 1994 – 1998. This study identified the major benthic communities in the Estuary, and the data were used to develop an assessment method to evaluate possible benthic impacts from sediment contamination. Benthic indicators of sediment contamination are being further refined under the Exposure and Effects Pilot Study (see below).



Sediment Toxicity Testing

The RMP began using the amphipod *Eohaustorius estuarius* for sediment toxicity monitoring in 1993. However, it is not a resident species. Another amphipod, *Ampelisca abdita,* is often dominant in benthic samples in the Estuary. This special study was conducted to develop a resident species for use in RMP sampling. The study compared the two species sensitivities to contaminants and evaluated the efficacy of collecting and interpreting toxicity to *A. abdita.* That species is seasonal in abundance, making a reliable supply of organisms difficult. Further, resident specimens were comparatively tolerant of contaminated sediments. The use of *A. abdita* is currently being further investigated in the Exposure and Effects Pilot Study (see below).

RMP Committee Organization Chart

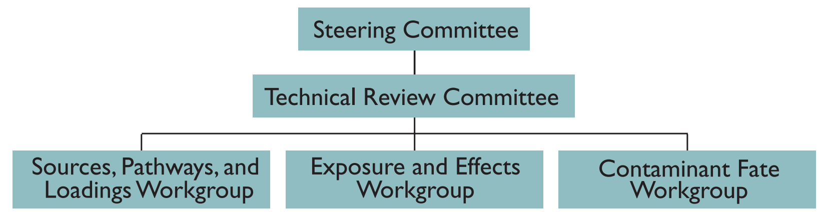
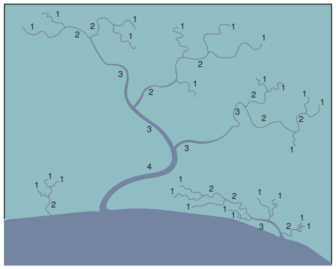


Figure 1. RMP committee organization. The three workgroups address the three main technical subject areas covered by the RMP. Workgroups consist of local scientists and regulators and invited scientists recognized as leaders in their field. The Workgroups directly guide planning and implementation of pilot and special studies. Activities of the Workgroups and the technical content of the RMP as a whole are directed by the Technical Review Committee. The Steering Committee determines the overall budget, allocation of program funds, tracks progress, and provides direction to the Program from a manager's perspective.

Wetlands Monitoring

The Wetlands Monitoring Pilot Study was conducted in 1995 and 1996. This study pioneered the use of the natural anatomy of Bay tidal marshes as a template for sampling chemical contamination. Taking this anatomy into account is essential to gathering data that can be compared among marshes. The number of samples collected was small, but the study provided a preliminary indication of the degree and variability of contamination of two Bay marshes. The results suggested that marsh sediments were more contaminated than sediments from nearby stations in the open Bay. Wetlands monitoring was not incorporated in the status and trends program because the Steering Committee decided to focus on development of the subtidal RMP. However, the Wetland Pilot did provide a foundation for the ongoing development of a Wetland Regional Monitoring program that is currently conducting much more intensive pilot monitoring studies of Bay wetlands using State and U.S. EPA funding.



Estuary Interface

The Estuary Interface Pilot Study was performed from 1996 – 2001, with funding provided by RMP and the City of San Jose. The goal of the study was to describe how surface runoff from two local watersheds might influence water quality in the Bay; this influence was found to be considerable. Concentrations of many priority contaminants in water and sediment were elevated at the two EIP stations relative to several other Bay segments, suggesting that the Guadalupe River and Coyote Creek watersheds were sources of these contaminants to the Lower South Bay. A particularly strong signal of mercury contamination from the Guadalupe River watershed was detected, tracing to historic mining activities in the New Almaden district. This information and other studies have identified inputs from the Guadalupe River watershed as a dominant influence on mercury in the South Bay, and led regulators to focus on this region in their efforts to reduce mercury contamination in the Bay through the TMDL process. The EIP Study also played an integral part in the development of a small tributaries loading study by the Sources, Pathways, and Loadings Workgroup. SFEI began a loading study on the Guadalupe River in late 2002 with funding from the Clean Estuary Partnership. The Estuary Interface Pilot Study was discontinued in 2002 when the status and trends program switched to a spatially randomized sampling design.

Fish Contamination

The Fish Contamination Pilot Study was performed in 1997, following up on a 1994 study conducted under the Bay Protection and Toxic Cleanup Program. Fish contamination monitoring was incorporated into the status and trends program in 2000. RMP fish contamination monitoring is the primary source of information used in evaluating the need for a fish consumption advisory for the Bay. The existence of this advisory is a principal reason that the Regional Board is developing total maximum daily loads (TMDLs) in an effort to reduce concentrations of mercury and PCBs in the Bay. Contaminant concentrations in sport fish provide an important target for tracking the necessity and effectiveness of TMDLs.

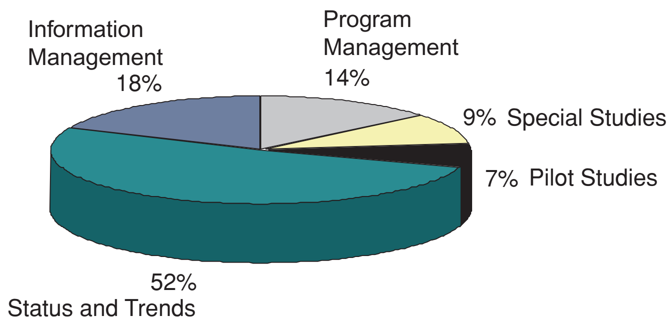
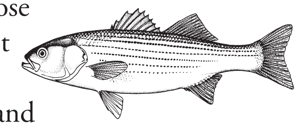


Figure 2. The RMP budget in 2003. Pilot and Special Studies accounted for 16% of the total budget.

Seafood Consumption

The RMP (as a special study) and the California Department of Health Services sponsored a study of fish consumption by Bay anglers in 1998 and 1999. About one in ten anglers was found to eat more than the amount recommended in the Bay consumption advisory. Asian anglers stood out as a group of concern due to their large numbers, consumption rates, and methods of preparation and consumption. Only about one quarter of the anglers interviewed had specific knowledge of the consumption advisory. Fostering increased awareness among those consuming Bay fish is the most rapid means of reducing risks posed by fish contamination, and represents an important complement to efforts to reduce contaminant concentrations. Education and outreach efforts based on the San Francisco Bay Seafood Consumption Study have been conducted.



Atmospheric Deposition

Atmospheric deposition was identified by the Sources, Pathways, and Loadings Workgroup as a potentially significant pathway for contaminant loading to the Bay. The Atmospheric Deposition Pilot Study, combining funding from RMP and the City of San Jose, was conducted from 1998 – 2000. Atmospheric deposition was found to contribute significant loads of contaminants, particularly mercury and PAHs. Atmospheric deposition of mercury directly to the surface of the Bay and entering the Bay through atmospheric deposition to watershed surfaces followed by stormwater transport amounted to a significant portion of the Bay mercury mass budget. Much of the atmospheric mercury load is attributable to global atmospheric mercury contamination. The study similarly suggested that atmospheric deposition of PAHs is significant in the overall mass budget for PAHs in the Bay, and should be a subject of management concern. The Atmospheric Deposition Pilot Study ended in 2000 having answered the fundamental questions posed at the beginning of the Study.

Episodic Toxicity

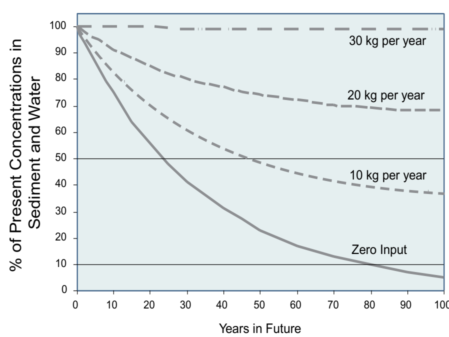
From 1996–2000 the RMP, with funds also contributed by East Bay Dischargers Authority, conducted the Episodic Toxicity Pilot Study. In the first years of the RMP, aquatic toxicity testing was performed on the same schedule and at the same locations as the water sampling for chemical analysis. Significant toxicity observed after storms in 1996 and 1997 led the Program to conduct more targeted sampling at the times (after storms) and places (tributary mouths) where toxicity was most likely to be observed. Study results indicated that toxicity was present in parts of the Bay primarily after runoff events. Some of the toxicity appeared to be associated with organophosphate pesticides, but other unidentified chemicals also appeared to be involved. Toxicity declined over the course of the Study, possibly due to decreasing use of organophosphate pesticides. Episodic toxicity evaluation became part of status and trends monitoring in 2001. For further discussion of aquatic toxicity testing in the RMP from 1993–2002, see page 27.

Exposure and Effects

In response to the new objective to measure contaminant effects, the RMP is conducting a pilot study on exposure and effects of contaminants. This five year (2002 – 2006) study is multifaceted, including a variety of different indicators: diving duck muscle (a human exposure indicator), cormorant and Forster's tern eggs (chemical trend indicators), hatchability of Forster's terns, least terns, and clapper rails (effects indicators), blood chemistry and biomarkers in harbor seals (exposure and effects indicators), effects studies in fish, aquatic and sediment toxicity testing of resident species (effects), and benthic community evaluations (effects). These indicators will be valuable in evaluating impairment of beneficial uses (through toxic impacts on wildlife and human health) and tracking effectiveness of management actions to reduce contamination in the Bay.

Fate Models

In 2001 a Mass Budget Model special study was performed. Mass budget models are valuable in many ways: summarizing the existing state of knowledge, synthesizing information from the RMP and other programs on contaminants in San Francisco Bay, predicting the response of contaminant concentrations in the Bay to management actions and natural processes, identifying and prioritizing data gaps, and communicating RMP results. Mass budget models have been developed for PCBs, PAHs, and organochlorine pesticides. This study also included development of a food web model for PCBs that links concentrations in sediment to concentrations in sport fish indicator species. The PCB mass budget and food web models are an integral part of the PCB TMDL. Model development and other data integration tasks became incorporated into the status and trends program in 2002.

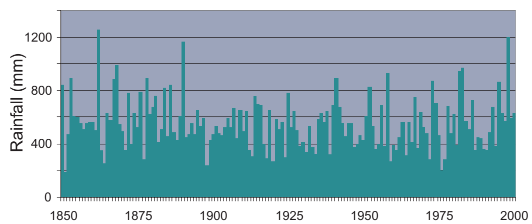


Surveillance Monitoring

Many of the contaminants regulated by the Regional Board and monitored in the RMP have been banned or strictly regulated for decades. In 2000 a surveillance component was added to the RMP to allow for more proactive management of Bay contamination. To initiate this surveillance monitoring, a special study was conducted to determine the presence of emerging contaminants in archived RMP samples. Many organic contaminants were found and are considered to be of potential concern, including flame retardants (polybrominated diphenyl ethers, or PBDEs), detergent ingredients (nonylphenol and alkylbenzenes), and constituents of plastics (phthalates). Based partially on these findings, PBDEs were added to the 303(d) watch list in 2001. In 2002, the emerging chemicals of concern were included in RMP status and trends monitoring to investigate their occurrence in recent samples. Those chemicals that are found at levels of concern will continue to be measured in annual RMP sampling. As emerging contaminants are identified in the RMP, the Regional Board will enlist the assistance of stakeholders to find the best ways of reducing or eliminating those that are a threat to human and wildlife health.

Sources, Pathways, and Loadings/Urban Runoff Literature Review

The Sources, Pathways, and Loadings Workgroup was formed in 1998 to produce recommendations for incorporating collection, interpretation, and synthesis of data on general sources and loading of trace contaminants to the Estuary into the RMP. Contaminant loading is a topic well suited to special studies, where focused, short-term projects can answer specific questions about the relative importance of inputs from different pathways. In 1999, the Sources, Pathways, and Loadings Workgroup conducted a literature review on loading of priority contaminants to the Bay and recommended a series of steps to assess the potential significance of contaminant loads to the Bay from urban runoff. One of the recommendations of the Workgroup was to develop and document our conceptual understanding of transport by stormwater through urban watersheds as a prelude to making actual measurements of loads. A second major literature review assembled information on climate and hydrology, suspended sediment, PCBs, organochlorine pesticides, and mercury and formulated recommendations for sampling small tributaries based on this information. The final report from this effort will be available in summer 2003. The review provided the conceptual foundation for the Clean Estuary Partnership's Guadalupe River Loading Study, which began measurement of loads from this high priority watershed in November 2002.



RMP 10 Year Anniversary 1993 2003

River Loads

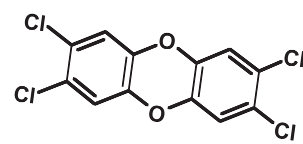
The Sources, Pathways, and Loadings Workgroup determined that loads to the Bay from the Sacramento and San Joaquin rivers are potentially significant components of the mass budgets for many contaminants. In 2002 SFEI began a three- year special study to estimate loads of priority contaminants at Mallard Island, a sampling location just downstream of the confluence of the two rivers. The loads will be estimated by establishing the statistical relationship between suspended sediment concentrations, which can be measured continuously, and contaminant concentrations, which must be measured less frequently due to the expense of chemical analysis. This approach will provide load estimates that characterize the large loads that occur over short timespans due to winter storms. Understanding the role of river inputs in contaminant mass budgets for the Bay will provide essential context for evaluating the potential effectiveness of actions taken to reduce Bay contamination, especially for mercury and DDT.

10 Year Synthesis

A highlight of the RMP in 2003 and 2004 is a special study to perform a thorough review of the first ten years of the RMP. In 2001 the RMP finished status and trends sampling employing the original fixed station design. The end of this initial chapter of the RMP is an appropriate time to perform a rigorous evaluation of trends indicated by the original status and trends program design. Ten years of monitoring also represents a substantial body of work for the other aspects of the RMP, and a synthesis of findings from these elements is also worthwhile at this time. In addition, the last synthetic overview of contamination in the Estuary was completed in 1991 (the San Francisco Estuary Project's Status and Trends Report on Pollutants: Davis et al. 1991), and Bay contamination, and understanding and regulation of Bay contamination, have changed considerably since that time. This study will produce a sequel to the 1991 Status and Trends Report.

CTR Monitoring

A short term, but significant, addition to the Program in 2003 is a special study to measure concentrations of priority pollutants in the Bay that are included in the California Toxics Rule (CTR), but have not previously been examined in ambient Bay waters. Some of the chemicals include dioxins, cyanide, phthalates, volatile and semi-volatile organics, and several trace elements. This study is being conducted in response to NPDES permit provisions for wastewater dischargers. This two-year special study began in 2002 and will end in 2003. Sampling to provide data needed specifically for NPDES permit development may continue to be part of the RMP after this study ends.



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The Pulse of the Estuary

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A Primer on Bay Contamination

Q: How contaminated is the Estuary?

A: Water and sediment of the Estuary meet cleanliness guidelines for most contaminants. In 2001, 90% of chemical concentrations measured in water were below their guideline, and 70% of chemical concentrations measured in sediment were below their guideline. However, a few problem contaminants are widespread in the Estuary, making it rare to find water or sediment in the Estuary that is completely clean. Of the recent (1997–2001) water and sediment samples collected by the Regional Monitoring Program (RMP), about 61% and 90% contained at least one contaminant at a level that failed to meet established guidelines, respectively. A fish consumption advisory remains in effect due to concentrations of mercury, PCBs, 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. Toxicity testing over the past 10 years has found that about 13% of water samples and 63% of sediment samples tested were toxic to at least one species of test organism. The 303(d) list and the 303(d) watch list are the official lists of contaminants of concern in the Estuary (see facing page).

Q: Are contaminants harming populations of organisms in the Estuary?

A: 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 contaminants above water and sediment 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. 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. Assessments of benthic communities in the marine and estuarine regions of the Bay indicate that some areas may be impacted by contaminants. The RMP began a focused investigation of contaminant effects in 2002; results will begin to be available by the next *Pulse*.

Q: Is the contamination getting better or worse?

A: Over the long term, the Estuary has shown significant improvements in basic water quality conditions, such as the oxygen content of Estuary water, due to investments in wastewater treatment (see article on page 15). Contamination due to toxic chemicals has also generally declined since the 1950s and 1960s. More recently, however, the answer to this question varies from contaminant to contaminant. 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, fish, and birds. Concentrations of DDT, chlordane, and other legacy pesticides have declined more rapidly and may soon generally be below levels of concern. On the other hand, concentrations of chemicals in current use, such as pyrethroid insecticides and polybrominated diphenyl ethers (PBDEs) are suspected to be 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.

Q: Do we know how to clean up the Estuary?

A: There are three general approaches to Estuary clean-up.

1. Reducing the entry of additional contaminants is essential. The Estuary acts as a long term trap for persistent contaminants; once contaminants enter the Estuary it takes a very long time for them to exit. Preventing contaminants from entering the Estuary is therefore imperative. Preventing a contaminant from entering the Estuary requires knowledge of its source or an interceptable part of its path to the Estuary. We are developing detailed descriptions of the sources, pathways, and repositories of contamination for several contaminants of concern. Much of this effort is in response to the Clean Water Act's requirement to develop contaminant clean-up plans known as Total Maximum Daily Loads (TMDLs, see page 11). While known contaminant problems are being addressed by TMDLs, surveillance monitoring is conducted in the RMP in an effort to provide an early warning for contaminants of emerging concern and allow for management actions to nip potential problems in the bud.

2. Removing some masses of contaminants 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 contaminants to degrade and disperse naturally is necessary. Time will always be a large part of the remedy, naturally reducing the large quantity of contaminants 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 (see page 21), burial is not occurring. For persistent contaminants found in large amounts in the sediments of the Estuary, such as mercury and PCBs, the time required to see change will be decades.

The 303(d) List

The San Francisco Regional Water Quality Control Board identifies contaminants of concern in the San Francisco Estuary based on RMP monitoring results and other information. Creation of an impaired water bodies list is required under section 303(d) of the federal Clean Water Act.

The list divides the Estuary into segments and their tributaries that are impaired due to contaminant concentrations that exceed load criteria and impact beneficial uses. The list is revised every four years. In February of 2003 the State Water Resources Control Board (SWRCB) approved the 2002 303(d) list for impaired water bodies within California, including the waters of the Estuary.

This proposal is now under review by the US Environmental Protection Agency, Region IX. The proposed revisions no longer consider copper and nickel as contaminants of concern in the Estuary, except at the mouth of the Petaluma River. Another contaminant of concern in the Petaluma River is diazinon. Stege Marsh in Richmond, Mission and Islais Creeks in San Francisco, and Peyton Slough in Martinez are included in the 303(d) list as impaired due to sediment toxicity.

This is the proposed list for the Estuary and its major tributaries:

Trace elements: Copper (Petaluma River mouth), Mercury, Nickel (Petaluma River mouth), Selenium
Organochlorine pesticides: DDT, Chlordanes, Dieldrin
PCBs
Diazinon
Others: Sediment Toxicity, Dioxins, Furans, Siltation, Pathogens, Nutrients, Exotic species

Potential Threats

The Regional Board, as part of developing the revised 303(d) list, also created for the first time a 303(d) "watch list" of potential threats to water quality. This is a list for contaminants where anecdotal information suggests they may be causing impairment but either the available data are inadequate to draw a conclusion, or the success of the existing regulatory program to control the contaminant is uncertain. Placement on this list is intended to trigger research so more informed decisions can be made in the future. The creation of this new preliminary list was prompted by the National Research Council. At the request of Congress, the NRC reviewed the TMDL process and suggested that this "preliminary list" be developed in addition to the 303(d) list.

This is the preliminary list for 2001 for chemical contaminants in the Estuary:

Copper: San Francisco Bay
Nickel: San Francisco Bay
PAHs: San Francisco Bay
PBDEs: San Francisco Bay
Sediment Toxicity: Central Basin in San Francisco;
Castro Cove in Richmond; Oakland Inner Harbor; San Leandro Bay

www.swrcb.ca.gov/~rwqcb2/download/Tmdl.pdf