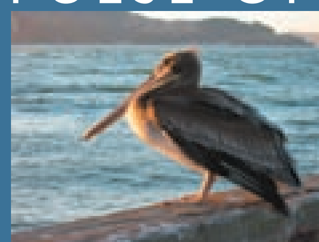
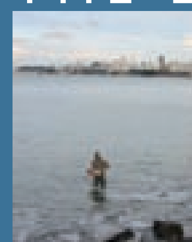
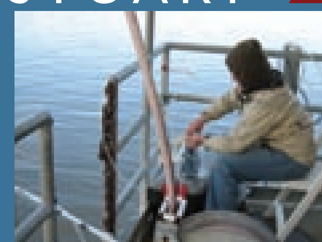
PULSE OF THE ESTUARY 2005

Monitoring and Managing Water Quality in the San Francisco Estuary

San Francisco Estuary Institute

About This Report

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

A highlight of this issue of *The Pulse* is an article by Rainer Hoenicke (page 4) describing a process of articulating the scientific questions that water quality managers need to have answered. The management questions developed through this process will provide specific guidance for the design and evaluation of the RMP over the next five years. The article also provides a summary of the lessons that have been learned over the past ten years through RMP efforts to answer past sets of management questions.

One of the challenging water quality issues managers will face over the next few years is monitoring and minimizing the impacts of the large tidal marsh restoration projects that are now beginning (page 72). Wetlands, including tidal marshes, are sites of relatively high production of the problematic form of mercury, methylmercury (page 21). In addition, tidal marsh restoration will affect the sediment budget of the Bay (page 58) by withdrawing more sediment from the ecosystem and accelerating erosion of sediments deposited on the Bay floor and in marshes. These remobilized sediments may be relatively polluted and have a negative influence on Bay water quality.

A panel of experts conducted a peer review of the RMP (page 12) that was completed in 2004. One of their recommendations was to place a greater emphasis on evaluating effects of pollutants, and this is captured in the new management questions. Several recent studies suggest that pollutants may affect survival of early life stages of three important fish species: striped bass (page 22), Sacramento splittail (page 64), and white sturgeon (page 64).

Emerging pollutants will also be an area of emphasis over the next five years. The RMP will be tracking trends in concentrations of polybrominated diphenyl ether (PBDE) flame retardants (page 32), which have been increasing rapidly in the Bay food web in recent years and reach world-record concentrations in the Bay. Another important class of emerging pollutants are pyrethroid insecticides (page 24), which are on the increase as a replacement for organophosphate insecticides such as diazinon.

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

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.

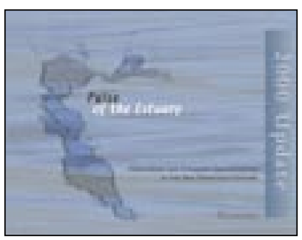
This report should be cited as:
San Francisco Estuary Institute (SFEI). 2005. The Pulse of the Estuary: Monitoring and Managing Water Quality in the San Francisco Estuary. SFEI Contribution 411. San Francisco Estuary Institute, Oakland, CA.

Short on time? The figures and captions provide key findings in a nutshell.

Table of Contents

Table of Contents (continued)

Past Pulses



2002

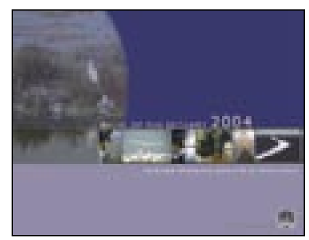
Feature articles:

- 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

2003

Feature articles:

- Lessons from Monitoring Water Quality in San Francisco Bay
- Sediment Dynamics Drive Contaminant Dynamics
- Ten Years of Testing for the Effects of Estuary Contamination
- Ten Years of Pilot and Special Studies: Keys to the Success of the RMP



2004

Feature articles:

- Long-Term Trends in Metal Contamination in San Francisco Bay Water and Sediment
- Lessons Learned About Metals in the Estuary: The Importance of Long-Term Clam Accumulation Data
- In Pursuit of Urban Runoff in the Urbanized Estuary
- The San Francisco Bay Water Quality Index: A Tool to Communicate Progress Toward Reaching Environmental Standards

Recent developments in water quality management in the Estuary

Management Update

- Adapting the Regional Monitoring Program to Answer the Important Questions
- The RMP Review
- Update on TMDLs from the Water Board

Adapting the Regional Monitoring Program to Answer the Important Questions

Rainer Hoenicke (rainer@sfei.org), San Francisco Estuary Institute

Key Points

- In the past ten years the RMP and other programs have greatly advanced the state of knowledge regarding spatial patterns, temporal trends, sources and loadings, effects of pollutants in the Bay, and the degree of impairment of beneficial uses
- A new objective has been added to the RMP that explicitly addresses the need to use our knowledge about ecosystem processes and human activities to forecast ecosystem recovery and pollution trends
- Based on our accumulated knowledge and emerging concerns, an updated set of management questions has been developed that provides specific guidance for the design and evaluation of the RMP over the next five years

Adaptive management, referred to in the TMDL context as "adaptive implementation," is central to the approach being taken to manage water quality in San Francisco Bay. One of the key steps in an adaptive water quality management program is to periodically and critically evaluate the extent to which monitoring and special study results, carefully interpreted, were able to answer management questions. A second step is to use the accumulated scientific information to refine current questions and develop new ones that are relevant to the goal of beneficial use protection and restoration. In the past year, the parties involved in the RMP took a look at the lessons learned during more than a decade of monitoring and special study results. They subsequently evaluated to what extent the Program objectives should be modified, and how the management questions should be adjusted based on our new level of understanding. The Committees guiding the RMP also reviewed the basic assumptions underlying the Water Board's needs to successfully manage their regulatory and incentive-based beneficial use protection and restoration programs.

Our Current Working Assumptions

The Clean Water Act was set up to deal with a multitude of stressors through its definition of "pollution" in Section 502(19) - "the man-made or man-induced alteration of the chemical, physical, biological, and radiological integrity of water." For the first 25 years of Clean Water Act implementation in the Bay-Delta, much regulatory emphasis was placed on protecting the "chemical integrity" of water, resulting in considerable improvements in the condition of the Estuary. However, one major weakness of the current regulatory framework, as it exists today in the U.S. and California, is that it is not well suited to preventing new persistent and bioaccumulative substances from becoming the "legacy pollutants" of the future.

In addition, it is now recognized that, quite often, limiting factors to beneficial use attainment appear to fall into non-chemical stressor categories (such as freshwater flow diversion, habitat alteration, and introduction of exotic species). For adaptive management to work, evaluation of non-chemical stressors needs to be incorporated into monitoring approaches. The following updated working assumptions reflect the above perspectives.

1) We have an increasing understanding of the relative loadings of pollutants of concern from various sources and transport pathways and where to direct priority actions, but addi-

tional work is still needed for some pollutants and to extrapolate existing data to forecast future trends.

2) Many of the pollutants of concern found in the Estuary system are from historic inputs.

3) Persistent, bioaccumulative substances not yet regulated require increased attention both in terms of biological effects and loadings.

4) Comprehensive, watershed-based approaches to controlling ongoing inputs of pollutants of concern promise to be more effective than piece-meal "program-driven" approaches (e.g., NPDES, Water Quality Certification, Non-point Source Program, TMDL, etc.).

5) Protection and restoration of beneficial uses require a different and larger set of tools than those used to deal with specific pollutants of concern.

Our Current State of Knowledge

Since 1998, when the first edition of RMP management questions was developed, much progress has been made in filling information gaps (see **Table 1**). At that time, the Program Participants began a thorough overhaul of the RMP, beginning with a revision to the Program objectives. This second generation of objectives that guided the RMP from 1998 through 2004 were:

1. Describe patterns and trends in contaminant concentration and distribution;
2. Describe general sources and loadings of contamination to the Estuary;
3. Measure contaminant effects on selected parts of the Estuary ecosystem;
4. Compare monitoring information to relevant water quality objectives and other guidelines; and
5. Synthesize and distribute information from a range of sources to present a more complete picture of the sources, distribution, fate, and effects of contaminants in the Estuary ecosystem.

The 2003 RMP Review (see page 12) indicated that the Program has responded well to the suggestions outlined in the 1997 Program Review. Although the 2003 Review Panel did not explicitly suggest that Program objectives be modified, the Panel stated "…that the Program must continue to evolve to ensure its long-term relevance."

Table 1 summarizes how the specific management questions derived from second generation objectives 1-4 were addressed, and what we have learned since then. Please note that the "lessons learned" represent very simplified highlights that are not based on RMP data alone but also on numerous complementary studies. They represent the starting point for subsequent management question refinement.

Thanks to the development and application of conceptual models and predictive models for most of the 303(d) pollutants, general knowledge about loadings, transport processes, pathways, source categories, and pollutant fate has increased considerably in the last five years. Water quality managers now generally recognize the following points.

- The capacity of the Estuary to degrade, bury, or dilute has historically been greatly exceeded for a number of pollutants (e.g., Hg, PCBs).
- New inputs need to be reduced below the Estuary's assimilative capacity.
- Past problems may take decades to rectify even after reductions of controllable sources are implemented.
- The large reservoir of pollutants in sediment poses significant constraints on recovery rates for some contaminants.
- Management actions in the watershed have effectively reduced inputs and exposure to certain pollutants, such as organophosphate pesticides.
- Certain emerging pollutants are entering the system faster than they can be degraded or removed, similar to what happened with PCBs and other persistent synthetic organics in the past. We don't know at this point when we will reach assimilative capacity for those pollutants, or if we have already exceeded it.

These kinds of lessons are re-shaping the questions that water quality managers are asking. The information needs have also become more complex as a result of several fundamental shifts in how water quality and associated beneficial uses are managed. These include:

1. Legal requirements to systematically deal with pollutants on the 303(d) list;

Assimilative Capacity: The capacity of a natural body of water to receive wastewaters or toxic materials without deleterious effects and without damage to aquatic life or humans

2. Demand for more quantitative cost-benefit analyses in times of shrinking budgets;
3. Requirements to link expenditure of bond funds by grant recipients in the Bay Area with performance measures/indicators;
4. Broad information needs at landscape and river-basin scales to evaluate water quality management program performance statewide; and
5. The emergence of additional complementary monitoring efforts with similar assessment questions and objectives (e.g., CBDA Ecosystem Restoration and Watershed Programs, DFG Resource Assessment Program).

The parties involved in the RMP evaluated the 1998 Program objectives and determined that new and emerging information needs require adjustments. As a result, an additional objective was proposed based on the advances in our understanding in recent years. The new objective explicitly addresses the need to use our knowledge about ecosystem processes and human activities to forecast ecosystem recovery and pollution trends. As revised through a joint Technical Review Committee and Steering Committee effort, the new RMP Objectives are outlined on pages 10 and 11.

A new RMP objective explicitly addresses the need to use our knowledge about ecosystem processes and human activities to forecast ecosystem recovery

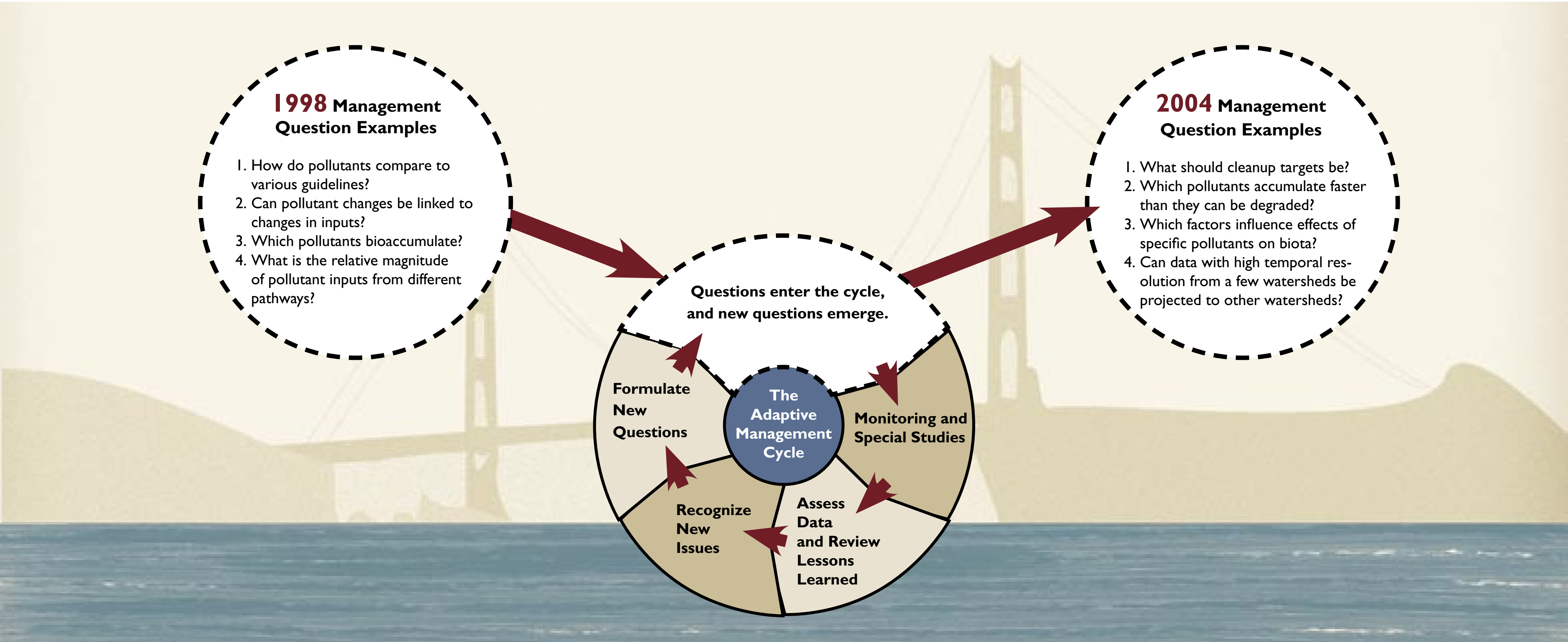


Table 1. First generation RMP objectives and their outcomes

Objective 1: Describe Patterns and Trends

Management Question	Monitoring and Study Approaches	Lessons Learned
How do contaminant levels change over the long term?	• Analysis of data from old RMP sampling scheme • New sampling design implemented • Ten-year synthesis	• Few trends discernible. Recovery for most legacy pollutants expected to be very slow. • PCB declines of about 60% in the past 20 years. • Legacy pesticide declines have been more rapid than PCBs. • Little change in mercury in fish tissue over the past 30 years. • PBDEs in human tissue are among the highest in the US, and concentrations are on the rise in Bay seals, birds, and fish. • Little change in PAH concentrations. • Too few data on dioxin. • Diazinon concentrations have declined. • Selenium, copper, and nickel show no apparent trend. • Silver declines in the South Bay since the 1970s have been dramatic. • Particle-associated pollutant patterns in water are primarily driven by sediment resuspension and to a lesser extent by loadings from the surrounding watersheds.
Can those changes be linked to changes in inputs?	• RMP data complemented by large USGS database and other data sources • Ten-year synthesis	• For some pollutants, yes. For others, diffuse distribution in surrounding watersheds and existing sediment reservoir will obscure linkage to changing inputs. • Major reductions in use and discharge of some pollutants coincide with decreases in surface concentrations in cores from depositional areas of the Estuary. • Conclusions are limited by lack of actual data on trends in inputs. Many input streams are difficult to measure (e.g., urban stormwater inputs). • Changes in PCBs and legacy pesticides can be qualitatively linked to bans. • Diazinon changes qualitatively linked to declining use. • PBDE increases qualitatively linked to increasing use. • Mass budget modeling is helping evaluation of links between inputs and recovery.
What is the relationship between pollutant trends and patterns seen in the "spine" and those in the shallower margins of the Estuary?	• New RMP sampling design implemented that includes sampling of shallows, augmented by site-specific clean-up studies	• Too early to tell by how much, but margins contain numerous spots with elevated concentrations. A few data points from the early BPTCP indicate that margins may have higher concentrations than deeper areas.
How are spatial patterns and long-term trends affected by estuarine processes?	• Mass budget modeling work on PCBs, PAHs, legacy pesticides - RMP data placed in context of USGS, IEP, CBDA, and other data	• Seasonal and inter-annual variability in flow has a discernible influence on contaminant distribution, concentrations, and uptake by and effects on biota. • Dominant processes identified through modeling include degradation, sediment dynamics (erosion/deposition and mixing), and outflow through the Golden Gate.

First generation RMP objectives and their outcomes

Objective 2: Describe General Sources and Loadings

Management Question	Monitoring and Study Approaches	Lessons Learned
What proportion of the contaminants in each Estuary segment are contributed by point source outfalls, storm drains, large and small tributaries, etc.?	• Literature reviews on loadings in general and urban runoff in particular • Initiation of RMP field studies on loads from the Central Valley, small tributaries, and atmospheric deposition • Formation of CEP • Development of conceptual and predictive mass budget models for most pollutants of concern • Non-RMP studies on loads from point sources, small tributaries, and stormwater • TMDL reports have compiled data on major pathways	• Small tributaries and Delta outflow are the major sources of mercury. • New PCB inputs to the Bay are largely from urban runoff. • Remobilization of PCBs, mercury, and other legacy contaminants from in-Bay hotspots and buried sediment are other major pathways. • Large natural contributions of certain metals come from geologic formations in the watershed (e.g., Ni, Cr). • Understanding of relative importance of different pathways for 303(d) pollutants much improved in the past few years. • Insufficient knowledge about sources of emerging 303(d) pollutants such as PBDEs.
How do contaminants move and transform after they enter the Estuary?	• Focus on Cu and Ni via impairment assessment studies • Literature synthesis as part of conceptual and numeric model development for 303(d) pollutants • Movement well described for PCBs and other organics by mass budget and food web models	• Large data gaps remain for Hg, PAHs, and emerging pollutants. • Cu and Ni tend to be largely unavailable to biota. • Increased understanding about remobilization potential via erosional processes due to mass budget modeling. • PCBs apparently don't degrade much. Legacy pesticides and PAHs are degraded more rapidly. • Mercury transformation to methylmercury is a key process driving impairment and is not well understood. • PBDE degradation processes are a major data gap. • Degradation rates of persistent organics in general are a major information gap.
At what spatial and temporal resolution should loadings and changes in upstream contaminant inputs due to pollution prevention efforts be monitored?	• New sampling design and special studies implemented • Further refinements necessary, especially monitoring integration with CVRWQCB • Mallard Island Study and Guadalupe River Study have established a strong foundation regarding temporal resolution	• Answers are pollutant-specific. For primarily water-soluble, short-lived pesticides, temporal and spatial resolution should be higher than for more persistent, particle-associated pollutants. • Much transport of particle-associated pollutants occurs during peak flows of a few large storms, requiring highly targeted sampling in a temporal sense. Sampling high flow years will be critically important. • Spatial resolution not yet determined. PCB modeling suggests an emphasis on loading to the South Bay would be appropriate.
What are the background concentrations of contaminants in the Estuary from natural sources?	• Data synthesis from coring data and literature • Special studies in Santa Clara Basin and South Bay	• Most metals are enriched above background in Estuary sediments, with the exception of Ni and Cr which are naturally elevated in the Bay and its watershed.

Objective 3: Compare Data to Guidelines

Management Question	Monitoring and Study Approaches	Lessons Learned
Which contaminants should be monitored?	• Review of RMP database • Special study on previously unknown synthetic organics • Special study on CTR contaminants	• Screening of chromatograms and effects data resulted in expanded list of trace organics. • Surveillance monitoring for emerging contaminants incorporated into RMP. • Certain metals in bivalve tissue scaled back.

First generation RMP objectives and their outcomes		
Management Question	**Monitoring and Study Approaches**	**Lessons Learned**
How do RMP data compare with relevant water, sediment, and tissue quality guidelines?	• Status and Trends Program modified but still designed to compare results to guidelines and recovery targets • Data reviewed annually in Annual Monitoring Results, the Pulse, reports on fish sampling	• 303(d) list pollutants frequently exceed their guidelines. • National criteria may not be appropriate for some contaminants; site-specific studies have resulted in revised water column objectives for Cu and Ni.
How do the various Estuary reaches compare to each other, in time and space, relative to guidelines?	• New sampling design implemented	• South Bay exceeds guidelines most frequently. • Northern and southern segments show exceedances more frequently than Central Bay.
Objective 4: Measure Contaminant Effects		
Which contaminants bioaccumulate in estuarine organisms to levels of concern?	• Incorporation of fish tissue analysis into status and trends monitoring • Initiation of multifaceted Exposure and Effects Pilot Study (EEPS) • Use of bird eggs to measure bioaccumulation and exposure • Analysis of duck tissue • Analysis of seal blood and fur • Non-RMP work on bird eggs by USFWS, UC Davis on seals, CISNET on birds and fish, *Potamocorbula* by USGS, HML on humans • The RMP has begun routine monitoring for PBDEs in transplanted bivalves, fish, and bird eggs	• Of the trace elements, Hg and Se bioaccumulate appreciably. • Several groups of synthetic organics (both legacy pollutants and certain trace organics still in use) bioaccumulate (PBDEs, musk ketones, nonylphenols). • Mercury, PCBs, legacy pesticides, dioxins and selenium exceed human health thresholds in sport fish. Increasing PBDEs also a concern in sport fish. • Mercury a clear continuing concern in clapper rails and terns. • PCBs a diminishing concern in bird eggs. • Selenium, mercury, and PCBs a human health concern in duck muscle. • PCBs a concern in seals. • Rising PBDEs a concern in birds, seals, and humans. • Selenium accumulation in *Potamocorbula* is a concern for predators. • Silver appears to have affected clam reproduction in the early 1990s, but has declined significantly since then.
What is the spatial and temporal extent of toxicity in the Estuary?	• Initiation of episodic toxicity study design for better identification of toxic events and possible causes • Shift in emphasis to sediment toxicity as a result of changes in pesticide use to more particle-associated pyrethroids	• Estuary waters do not tend to be toxic, and the RMP has documented a decrease in the incidence of aquatic toxicity observed in the tributaries during storm events between 1997 and 2001. • Estuary sediments continue to be toxic with no evidence of decrease. 63% of the samples tested were toxic to at least one test organism between 1997 and 2001.
Which contaminants cause effects in the Estuary?	• Initiation of expanded effects monitoring efforts through the EEPS • Re-design of toxicity monitoring • Comparisons of new exposure data with laboratory effects threshold levels • Non-RMP studies by USFWS on mercury in birds, UC Davis on organics in harbor seals, UC Davis on contaminant effects on larval striped bass • Small RFP issued for studies of effects on fish	• Strong possibility of population-level mercury impacts on clapper rails. • Indications of effects of PCBs on seals and birds. • Contaminants appear to affect larval development and survival in striped bass. • The RMP Benthic Pilot Study (and subsequent benthic studies) have developed a benthic assessment tool that can identify impacted benthic communities using a triad approach. • Indications of benthic community impacts of legacy pesticides. • Possible PBDE effects in seals.

New Management Questions

Current issues of concern, posed as management questions, are grouped below in relation to each of the new 2005 RMP objectives. These management questions provide more specific guidance for the design and evaluation of the many elements of the RMP.

1. Describe the distribution and trends of pollutant concentrations in the Estuary

1. Which pollutants should be monitored in the Estuary, in what media, and at what frequency?
2. Are pollutants of concern increasing, decreasing, or remaining the same in different media?
3. How are contaminant patterns and trends in the Estuary over time affected by remediation and source control or pollution prevention in the watersheds?
4. Do pollutant concentration distributions indicate particular areas of origin or regions of potential ecological concern?
5. What effects on beneficial uses or attainment of water quality standards will occur due to large-scale habitat restoration in the Estuary in decades to come?

This new generation of questions will guide the RMP during its next five years

2. Project future contaminant status and trends using current understanding of ecosystem processes and human activities

1. Can reasonably accurate recovery forecasts be developed for major segments and the Estuary as a whole under various management scenarios?
2. Can potential impairment and degradation be better anticipated in the face of projected changes in land and water use and management, as well as product use and disposal?
3. Which pollutant categories are predicted to accumulate in the Estuary faster then they can be assimilated?
4. Do pollutant trends reflect historical changes in use patterns, transport and transformation processes, or control actions?
5. How will the importance of each pathway change through time under various management and development scenarios?
6. What is the projected future loading of pollutants of concern under various management and development scenarios?
7. What are the likely consequences of various management actions or risk reduction measures?
8. Do pollutants show existing distributions that fit our current understanding or models of their origin, loads, and transport?
9. What changes in loadings or ecosystem characteristics (e.g., extent of restored tidal marsh, Estuary circulation and flushing, food web shifts) would reduce or increase pollutant exposures and effects?
10. How are distributions and long-term trends in pollutants affected by current and predicted estuarine processes (e.g. sediment erosion, deposition, river inflows)?

3. Describe sources, pathways, and loading of pollutants entering the Estuary

1. Where are/were the largest pollutant sources, in what context are/were these pollutants applied or used, and what are/were their ultimate points of release into the aquatic environment?
2. What are the circumstances and processes that cause the release of pollutants from both internal and external source areas?
3. Once released, how do pollutants travel from source areas to the Estuary, what are the temporal and spatial patterns of storage, and are they transformed along the way or after deposition?
4. What is the annual mass of each pollutant of concern entering the Bay from each pathway?
5. Can data with high temporal resolution from a few watersheds be projected to other watersheds and the Basin as a whole?
6. For each pollutant of concern, what forms are released from each pathway and what are the magnitude and temporal variation of concentrations and loadings?
7. How do loads change over time in relation to management activities?
8. What is the relative importance of pollutant loadings from different sources and pathways, including internal inputs, in terms of beneficial use impairment?

4. Measure pollution exposure and effects on selected parts of the Estuary ecosystem (including humans)

1. How are emerging problems reflected in exposure and effects measurements?
2. Which (co-)factors (e.g., food web structure) influence exposure and effects of specific pollutants on biota?
3. What ecological risks are caused by pollutants of concern?
4. What human exposure to pollutants of concern results from consumption of fish and game?
5. To what extent does exposure to multiple pollutants lead to effects?
6. Which forms of pollutants cause impairment?
7. To what extent do factors other than specific pollutants (invasive species, flow diversions, land use changes, toxic algal blooms) contribute to beneficial use impairment?

5. Compare monitoring information to relevant benchmarks, such as TMDL targets, tissue screening levels, water quality objectives, and sediment quality objectives

1. What percentage of the Estuary is supporting beneficial uses?
2. Which segments should be considered impaired and why, and how do segments compare in terms of recovery targets?
3. How can specific source limitations, controls, and mitigation be best linked to appropriate beneficial use endpoints and recovery targets?

6. Effectively communicate information from a range of sources to present a more complete picture of the sources, distribution, fate, and effects of pollutants and beneficial use attainment or impairment in the Estuary ecosystem

1. This objective applies to all of the questions listed under objectives 1 – 5.

This new generation of questions will guide the RMP during its next five years, setting the stage for adjustments to the monitoring program, designing special studies capable of testing specific hypotheses prior to implementing management actions or revising policies, and communicating key messages to policy-makers and the public.

The RMP Review

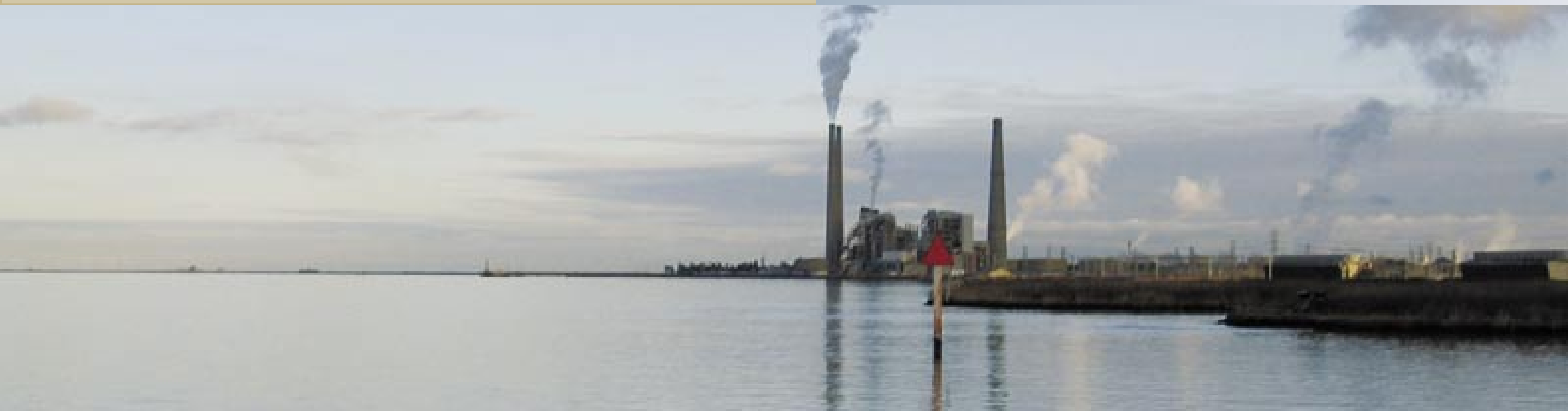
Every five years, the RMP conducts a comprehensive Program Review to supplement the regular technical and management oversight of the Program. These reviews evaluate the successes and shortcomings of the overall Program and recommend how the Program should be modified to improve its future effectiveness. The first review was held in 1998, and the Steering Committee recruited Dr. Alan Mearns (NOAA) from that Review to provide transition. Dr. Jerry R. Schubel (President, Aquarium of the Pacific, and leader of many national evaluations of coastal monitoring and policy) was chosen to chair the 2003 Review. Bob Berger (retired, East Bay Municipal Utility District), Dr. John Conomos (Interim Director, Bay-Delta Science Consortium), Dr. Perry Herrgesell (California Department of Fish and Game) and Dr. Stephen Weisberg (Executive Director, Southern California Coastal Water Research Project) rounded out the team.

The unusual partnership of a regulatory agency, the regulated community, and an independent scientific institution has demonstrated that "adaptive management" can work
— Jerry Schubel, Review Panel Chair

The 2003 Program Review Panel examined documents, conducted interviews with staff and stakeholders, and held two meetings. It came to the following overall conclusions.

- The RMP responded appropriately to the recommendations of the 1998 Review.
- The RMP should increase its emphasis on assessing biological effects of the chemicals RMP monitors, the transformation of data into information by combining RMP data and information with those from other sources, and developing mechanisms to ensure that RMP data and information are incorporated into the appropriate management decision-making processes.
- For the RMP to continue to evolve as one of the nation's best regional environmental monitoring programs, it must be embedded in a strong and highly regarded San Francisco Estuary Institute.

These conclusions were supplemented by three pages of detailed recommendations. The Review Panel's findings have been presented to the RMP governance committees. Each committee is responsible for evaluating and implementing specific recommendations, and in response you will be seeing changes in the RMP in the future. The full report is on the RMP website. Our thanks to the Review Panel and all the RMP members who participated in the Review.



Update on TMDLs from the Water Board

Dyan C. Whyte (DWhyte@waterboards.ca.gov) and Thomas E. Mumley, San Francisco Bay Regional Water Quality Control Board

During the past year we have made considerable progress on several TMDL projects. The Water Board adopted the San Francisco Bay Mercury TMDL in September, and we are nearing completion on seven other TMDL projects (**Table 1**). There are currently 270 San Francisco Bay Region listings on the State's 303(d) list of impaired waters. Upon completion of these TMDL projects that are scheduled for Water Board action by June 2006, we will have resolved over 100 impairment listings in the Region. A brief overview of each of these projects follows. In addition, projects to resolve Bay listings for selenium, diazinon/pesticide toxicity, and legacy pesticides are being developed via the Clean Estuary Partnership. Other projects in the works include TMDLs for mercury in the Guadalupe River Watershed, and sediment in San Francisquito Creek and Sonoma Creek. Information on these TMDLs and all our TMDL projects is available on our website – http://www.swrcb.ca.gov/rwqcb2/tmdlmain.htm.

Key Points

- It is anticipated that eight TMDL projects will be completed by June 2006 and will resolve over 100 of the 270 impairment listings for the region
- A Water Board hearing concerning a Basin Plan Amendment to establish and implement a TMDL for PCBs in the Bay is anticipated in January 2006
- Other TMDLs underway will address pesticide toxicity, sediment, and pathogens in Bay tributaries, and pathogens and mercury in Tomales Bay and Walker Creek

San Francisco Bay PCBs

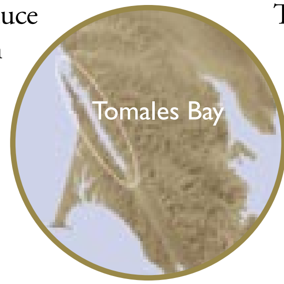
The goal of the San Francisco Bay PCBs TMDL is to reduce PCBs in aquatic life so that humans and wildlife can safely consume fish. Sources of concern include in-Bay hotspots and urban runoff. We are fortunate to have both the Regional Monitoring Program and the Clean Estuary Partnership to assist us in developing the scientific basis of the TMDL and evaluating implementation alternatives. This includes development of a model of PCB movement through the food web, a multi-box model of the long-term fate of PCBs in Bay water and sediment, and a risk reduction strategy. A Proposition 13-funded project led by the San Francisco Estuary Institute is also underway to evaluate methods to reduce loadings of sediment-associated pollutants (including PCBs) in urban stormwater runoff. In another Proposition 13-funded project the City of Oakland is identifying specific sources of PCBs and initiating cleanups and public outreach in a West Oakland watershed (Ettie Street drainage). We are currently getting input from the various stakeholders as we draft Basin Plan language to establish and implement the TMDL.

San Francisco Bay Urban Creeks Diazinon and Pesticide-Related Toxicity

The goal of San Francisco Bay Urban Creeks Diazinon and Pesticide-Related Toxicity Water Quality Attainment Strategy and TMDL is to reduce pesticide-related toxicity and protect aquatic life in all urban creeks. This effort is aimed not only at eliminating existing sources of such toxicity, but also preventing this toxicity from occurring in urban creeks in the future. Fortunately, urban uses of diazinon have been phased out, but unfortunately, replacement pesticides, particularly pyrethroids, may be even more toxic (see page 24). We are currently involved in an extensive stakeholder effort to obtain feedback on draft Basin Plan language. Many of the urban runoff programs are already implementing large portions of the implementation plan. A key challenge is to better coordinate how the California Department of Pesticide Regulation, U.S. EPA, and the Water Board regulate pesticides and water quality.

Napa River Sediment

The overall goal of the Napa River Sediment TMDL Project is to reduce sediment discharges and enhance and restore native fish populations in the Napa River Watershed. A crucial challenge in developing sediment TMDLs is distinguishing between naturally occurring and controllable sediment discharges. This Project confirmed that sediment discharges in the Napa River Watershed are linked to a decline in steelhead and salmon populations in the river. Sediment discharges are degrading steelhead spawning gravels in the upper watershed and salmon spawning and juvenile rearing habitat in the lower watershed. Land uses that may increase erosion, such as dirt roads, vineyards, and grazing, and actions that cause creek channels to erode their bed and banks are considered controllable and will be addressed by the TMDL.



Napa River and Sonoma Creek Pathogens

The goal of the Napa River and Sonoma Creek Pathogens TMDLs is to minimize human exposure to disease-causing pathogens (bacteria and parasites capable of causing disease). These TMDLs focus on protecting recreational water uses (fishing, swimming, and boating). We recently confirmed that septic tanks and urban runoff are key pathogen contributors in these watersheds, and livestock and grazing are localized sources.

TMDL Project	Project Report	Testimony Hearing
Tomales Bay Watershed Pathogens	Completed March 2004	April 2005
SF Bay Urban Creeks Diazinon and Pesticide Related Toxicity	Completed March 2004	August 2005
SF Bay PCBs	Completed January 2004	January 2006
Napa River Pathogens	May 2005	February 2006
Sonoma Creek Pathogens	May 2005	February 2006
Walker Creek Mercury	June 2005	March 2006
Napa River Sediment	April 2005	April 2006

Table 1. San Francisco Bay Region TMDLs Scheduled for Completion by June 2006.

Tomales Bay Watershed Pathogens

The goal of the Tomales Bay Watershed Pathogens TMDL is to minimize human exposure to disease-causing pathogens. Tomales Bay supports one of the few remaining commercial shellfish growing areas on the west coast, and the TMDL focuses on protecting shellfish consumers while balancing the desire to sustain agriculture in the watershed. Early actions are already underway. We are working closely with the County of Marin to improve its septic tank program, inspecting all regulated facilities, working closely with the National Park Service to better manage rangeland, dairies and recreational uses, implementing our dairy waste management program, and developing a mechanism to track and improve rangeland management.

Walker Creek Mercury

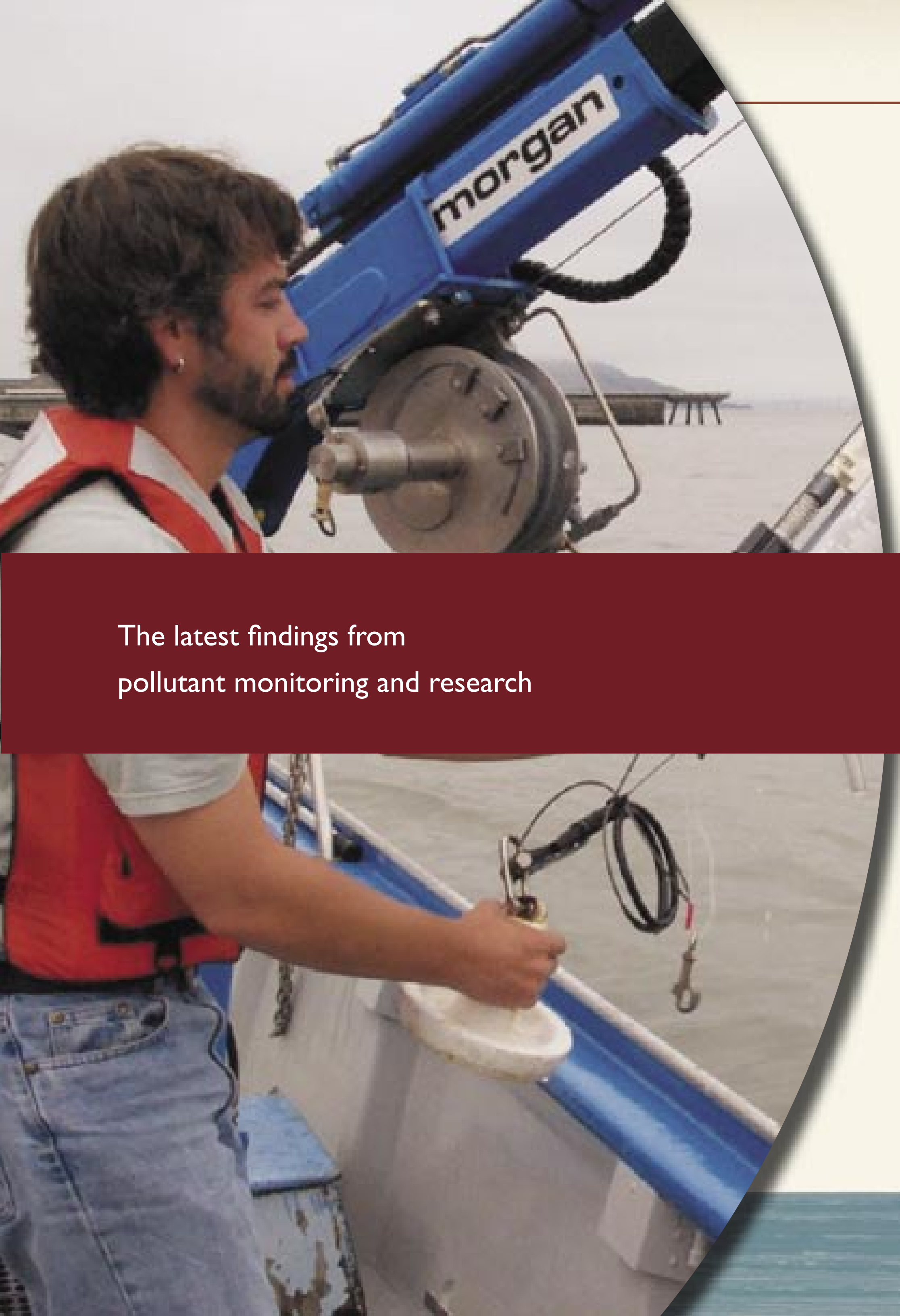
Walker Creek is a Tomales Bay tributary. The goal of the Walker Creek Mercury TMDL is to reduce mercury in aquatic life so that humans and wildlife can safely consume fish and shellfish from Tomales Bay. Early action on this TMDL began in 1998 when the Board, using funds from the State's cleanup and abatement account, partnered with U.S. EPA to cleanup the Gambonini mercury mine. Recent monitoring suggests that mercury loads from the mine site have decreased by 75% as a result of cleanup efforts. The Board and the public will be invited to attend a site tour this spring. A remaining implementation challenge for this TMDL is to address legacy mine wastes downstream of the mine site.

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.

For more information on TMDLs, visit these web sites:

San Francisco Bay Regional Water Board - www.swrcb.ca.gov/rwqcb2/tmdlmain.htm

U.S. Environmental Protection Agency - www.epa.gov/owow/tmdl/

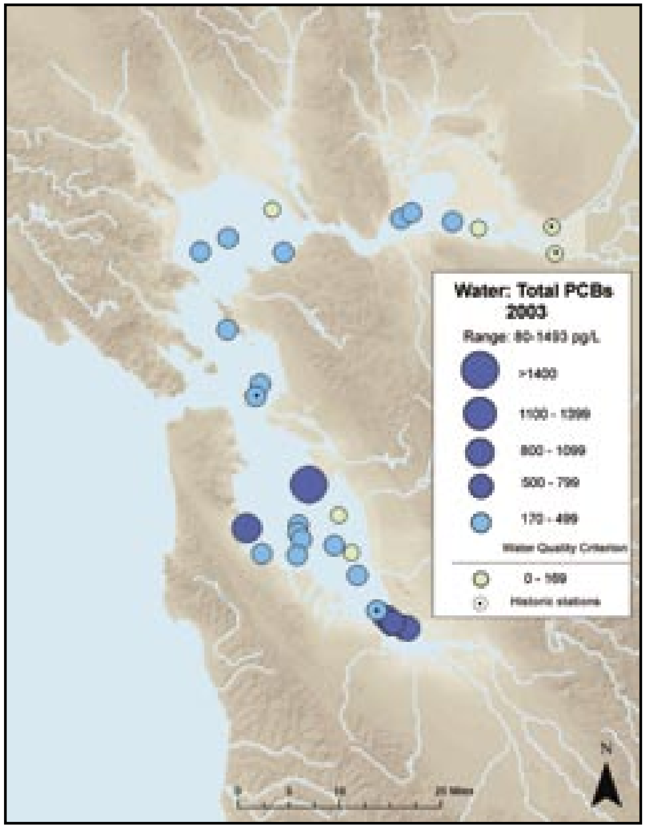


The latest findings from
pollutant monitoring and research

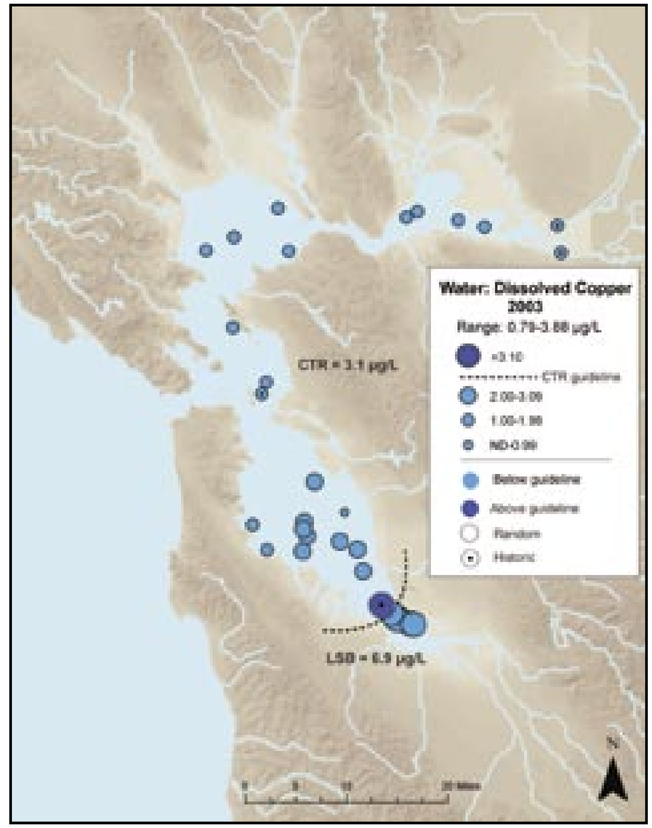
Status and Trends Update

- The Latest RMP Data
- Important Findings from Other Studies
- Water Quality Trends at a Glance

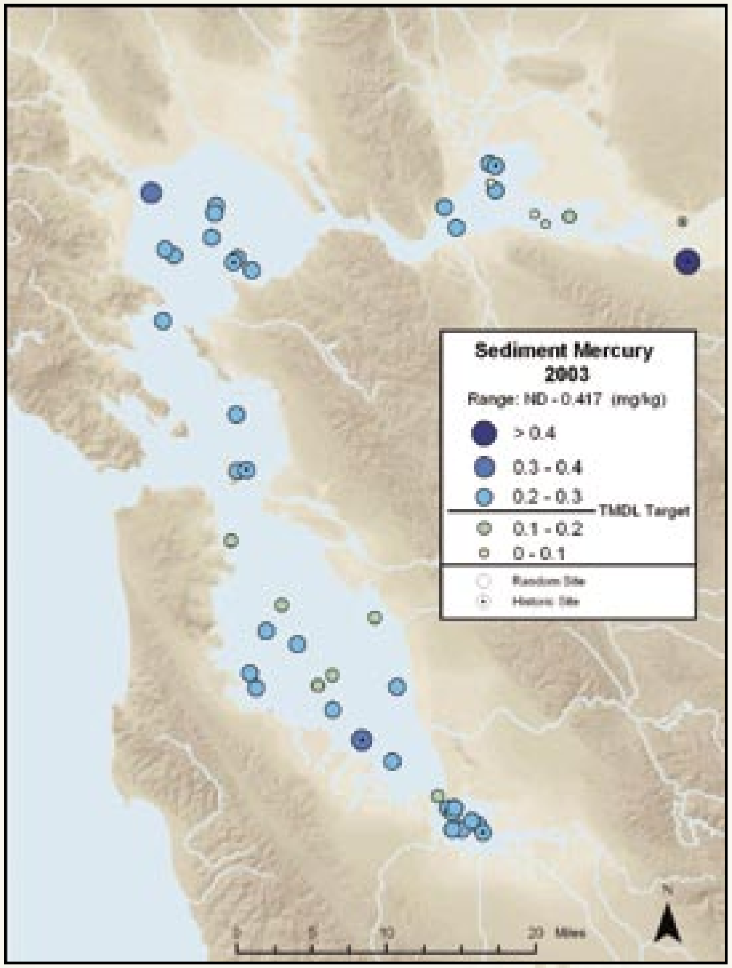
The Latest RMP Data



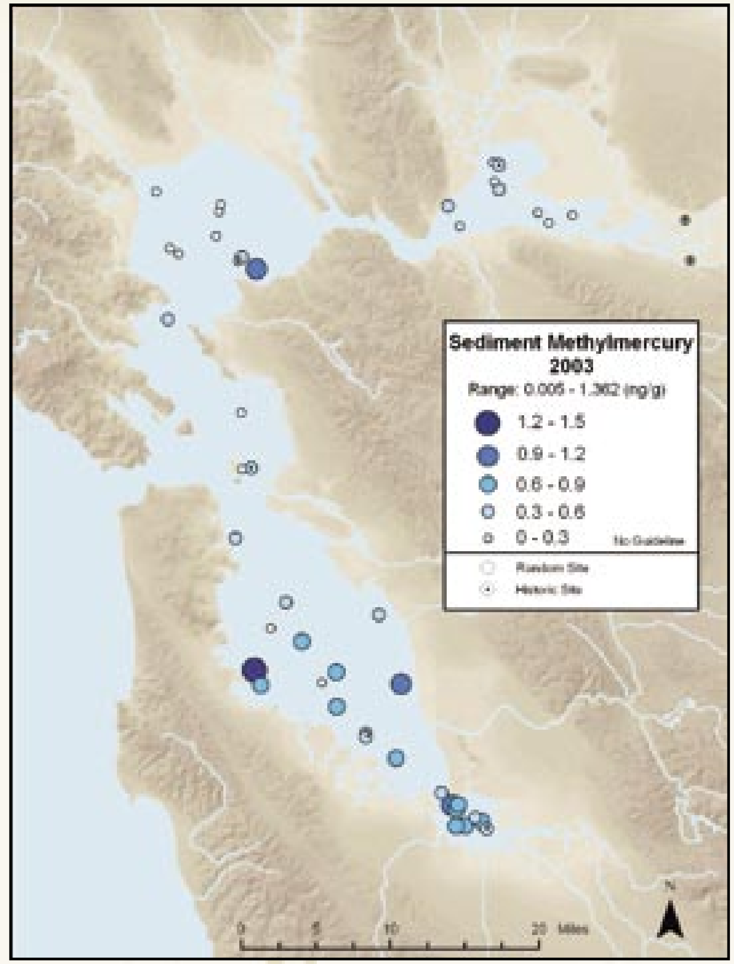
PCB contamination remains one of the greatest water quality concerns in the Estuary, and PCB clean-up is a primary focus of the Regional Water Quality Control Board. PCBs are a problem because they accumulate to high concentrations in some Bay fish and pose health risks to consumers of those fish. The water quality objective for PCBs in water is designed to prevent unacceptable accumulation of PCBs in humans who consume Bay fish. In 2003, this PCB water quality objective was exceeded in 24 of 27 samples (89%) collected from the Bay.



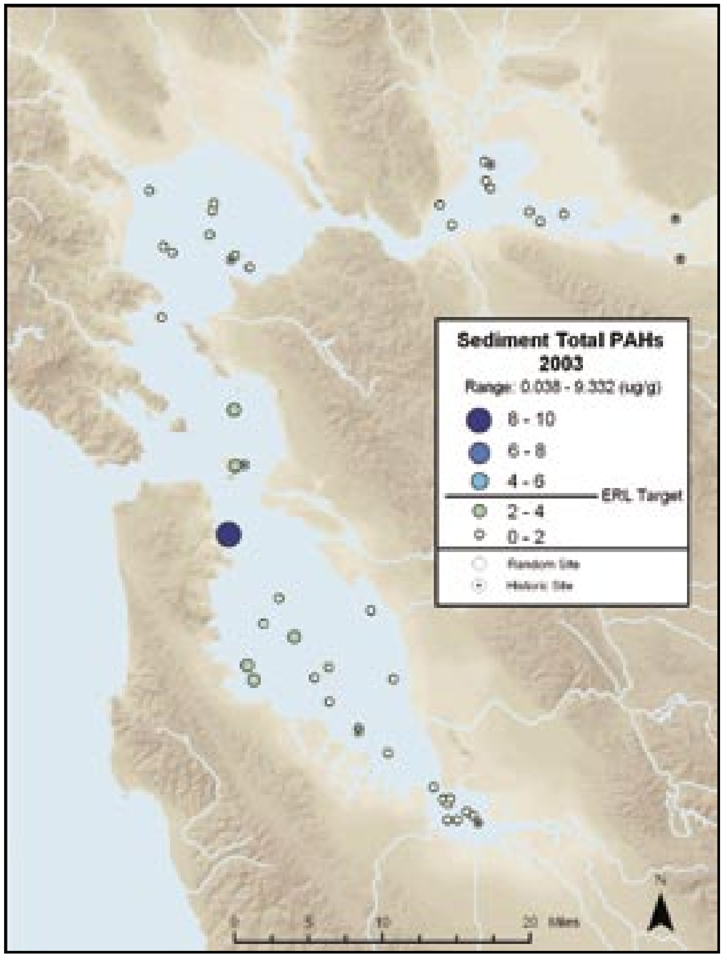
Copper was a major concern in the Estuary in the 1990s, as concentrations were frequently above the water quality objective. An evaluation of the issue by the Regional Board and stakeholders led to new water quality objectives for copper and nickel in the Lower South Bay, less stringent but still considered fully protective of the aquatic environment, pollution prevention and monitoring activities, and the removal of copper from the 303(d) list. In 2003 only one water sample, at the boundary of the South Bay and Lower South Bay segments, had a concentration exceeding the water quality objective. Concentrations in the Lower South Bay were high relative to the rest of the Bay, but well below the site specific objective for that segment.



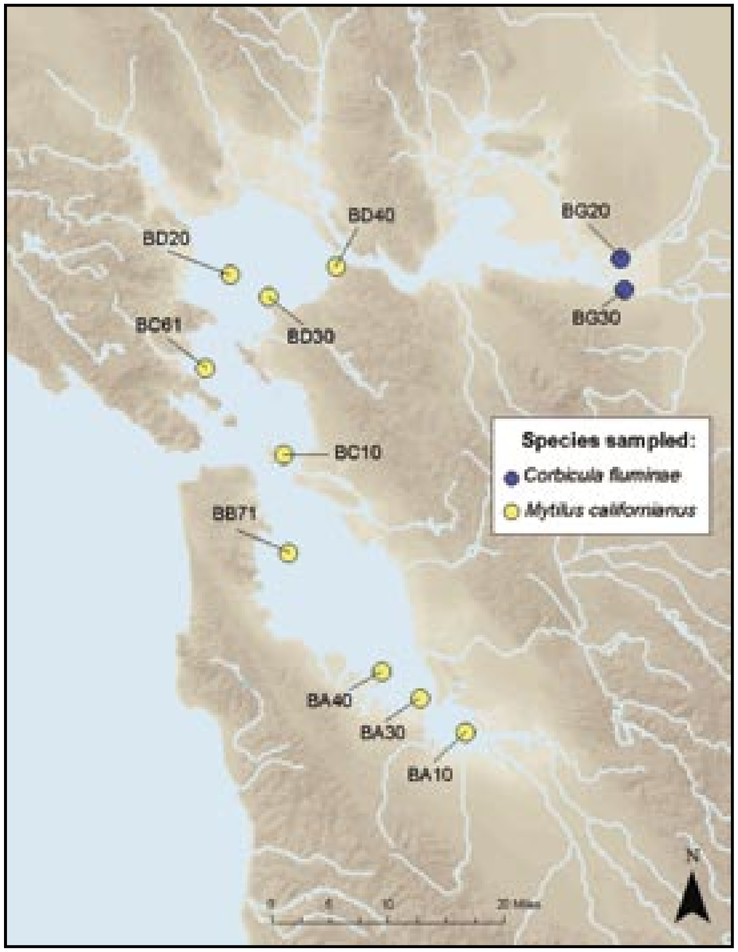
Mercury contamination is one of the top water quality concerns in the Estuary and mercury clean-up is a high priority of the Regional Water Quality Control Board. Mercury is a problem because it accumulates to high concentrations in some fish and wildlife species. The greatest health risks from mercury are faced by humans and wildlife that consume fish. The sediment target in the mercury TMDL is intended to prevent unacceptable concentrations in fish. In 2003, 35 of 47 (74%) of Bay sediment samples had concentrations higher than the mercury TMDL target of 0.2 mg/kg. Most samples were between 0.2 and 0.3 mg/kg. Only a historic fixed site on the San Joaquin River had a concentration above 0.4 mg/kg.



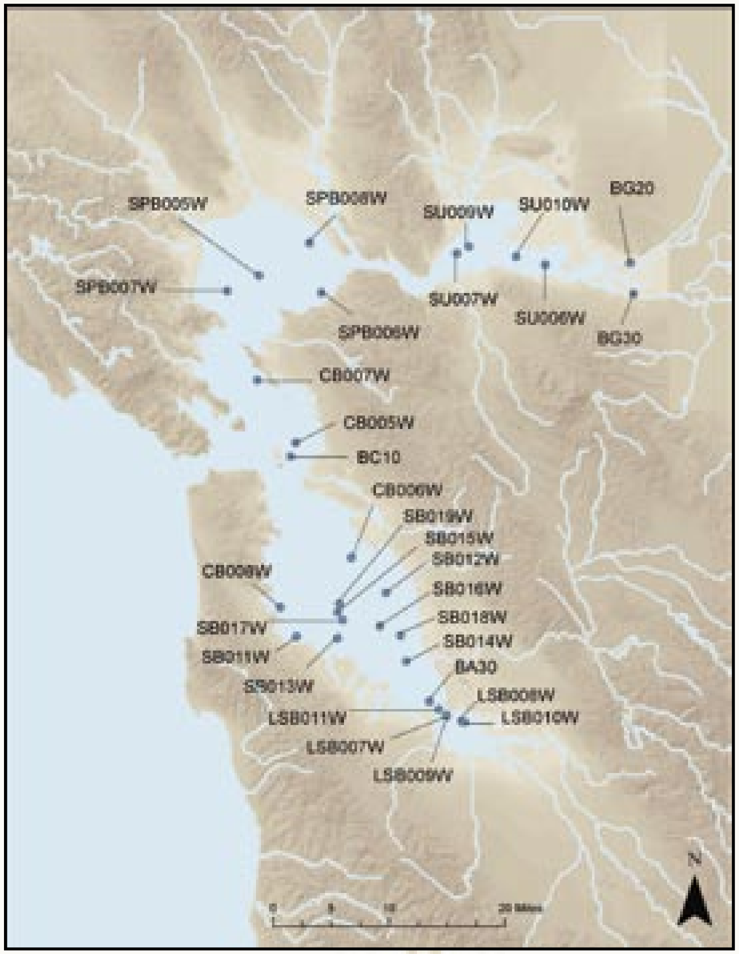
Mercury is converted to its most hazardous form, methylmercury, primarily by bacteria in sediment. Methylmercury production can vary tremendously over small distances and over short time periods, so this should be considered a snapshot of conditions in the Bay at the time of this survey in the summer of 2003. The highest concentration observed in this survey (1.36 ng/g) was found along the western shore of South Bay. No regulatory guideline exists for methylmercury in sediment.

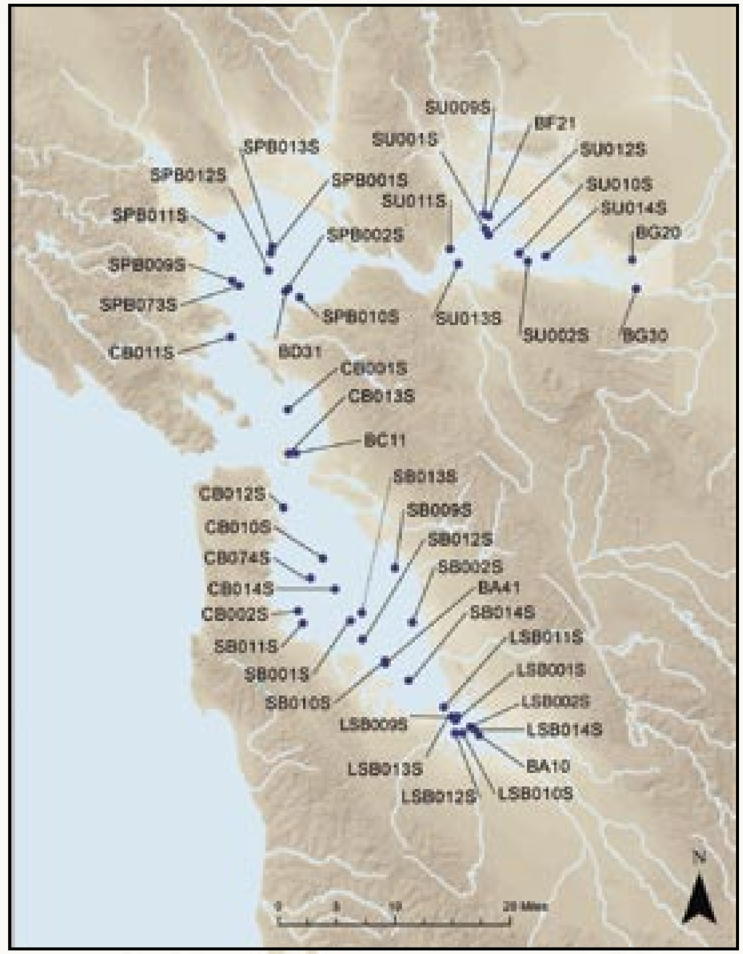


Continuing inputs of polycyclic aromatic hydrocarbrons (PAHs) to the Bay and improved understanding of PAH effects led to their inclusion on the 303(d) watch list. **PAH concentrations in Bay sediments in 2003 were generally below the ERL** ("effects range low"), a non-regulatory guideline indicating a threshold for possible effects on aquatic life. Only one sample exceeded the ERL, collected from the Central Bay segment along the San Francisco shoreline.



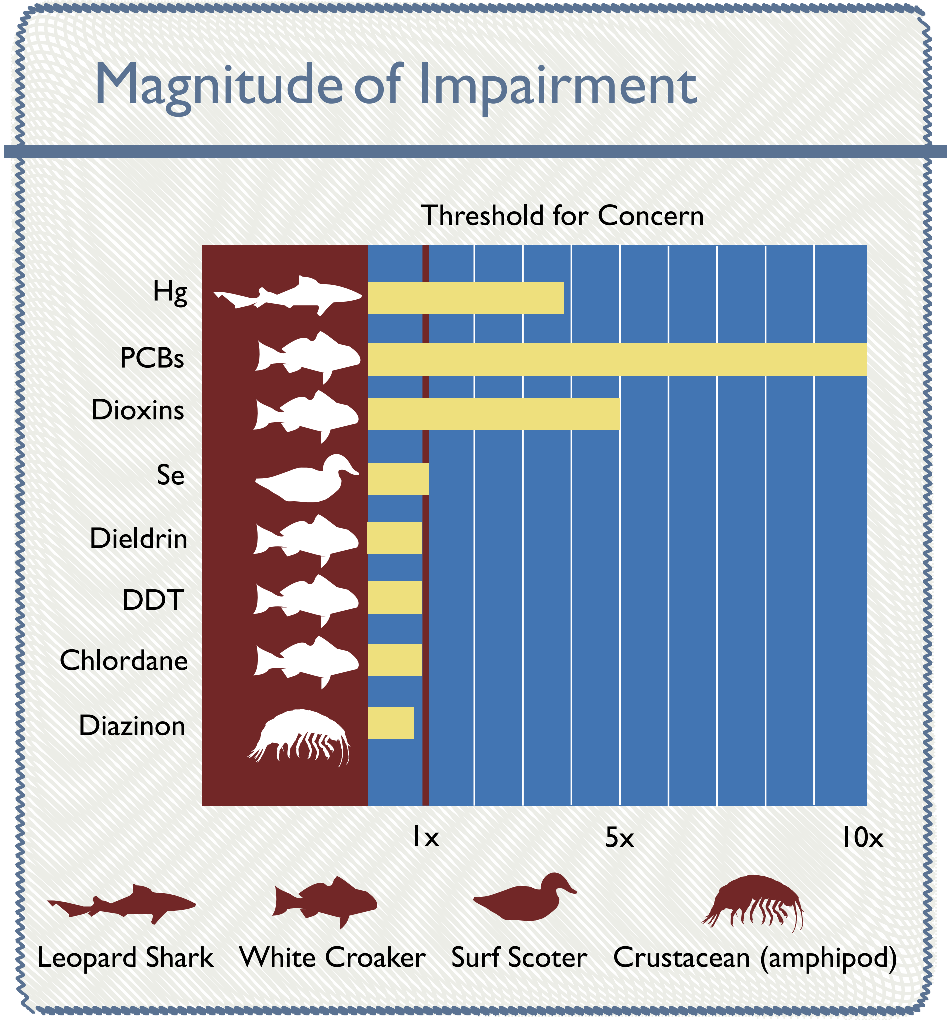
Sampling of mussels and clams is performed as an indicator of long-term trends in organic contamination. Mussels (transplanted *Mytilus californianus*) are sampled in most of the Bay, and clams (resident *Corbicula fluminea*) are sampled near the eastern edge of Suisun Bay. The bivalves are sampled at fixed locations to extend long-term time series that date back to the beginning of the RMP in 1993, and in some cases back into the 1980s.





Most RMP monitoring locations are chosen at random. In this scheme, the Estuary is divided into five regions and random locations are chosen in each of the regions. For sediment, eight random locations are chosen in each region each year. Some of these locations will be revisited in future years, to provide a consistent basis for measuring change over time. For water, four to ten random locations are chosen in each region each year. Choosing random rather than fixed locations means the results are representative of each region, rather than just particular locations within each region. A few historical fixed-site stations remain, for tracking long-term trends at those locations. Each site is sampled once each year, during the dry season. Site codes indicate Bay segments: SU=Suisun Bay, SPB=San Pablo Bay, CB=Central Bay, SB=South Bay, LSB=Lower South Bay. Codes beginning with "B" indicate fixed sites.

Important Findings from Other Studies

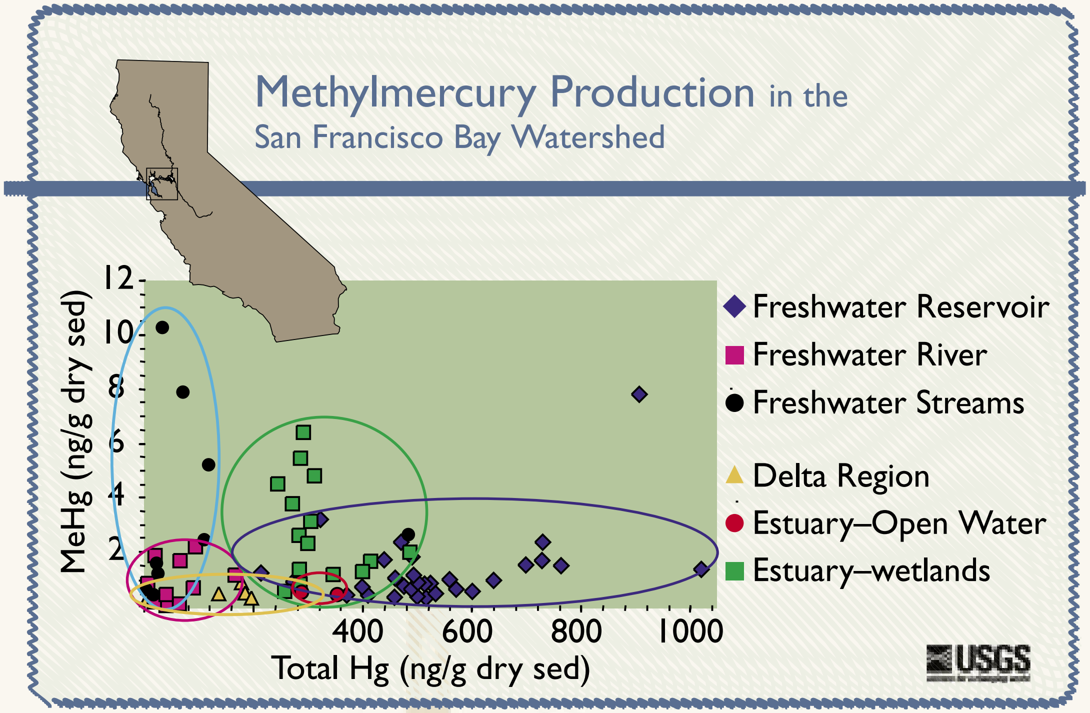


Summary of the degree of impairment of Bay water quality by high priority pollutants. The bars show how many times higher typical concentrations are in important indicator species relative to the appropriate threshold for concern. PCB concentrations in white croaker are the most elevated (ten times higher than the threshold), with approximately a 90% reduction needed to bring average concentrations down to the threshold. Dioxin concentrations in white croaker are also well above the threshold. Mercury concentrations in leopard shark are three times higher than the threshold. Selenium concentrations in surf scoter are near the threshold. Average concentrations of the pesticides dieldrin, DDT, and chlordane in white croaker are below the threshold. Diazinon concentrations are below the threshold for impacts to sensitive crustaceans.

Contact: Mike Connor, San Francisco Estuary Institute, mikec@sfei.org

Methylmercury versus total mercury in different aquatic habitats within the San Francisco Bay watershed. USGS researchers have measured mercury in sediments of aquatic ecosystems in northern California for the past decade. Comparison of methylmercury to total mercury in sediment provides an index of methylmercury production in the habitat sampled. **Data from these studies illustrate the association of wetlands in the Estuary with high relative rates of methylmercury production.** Freshwater streams also sometimes exhibit relatively high methylmercury.

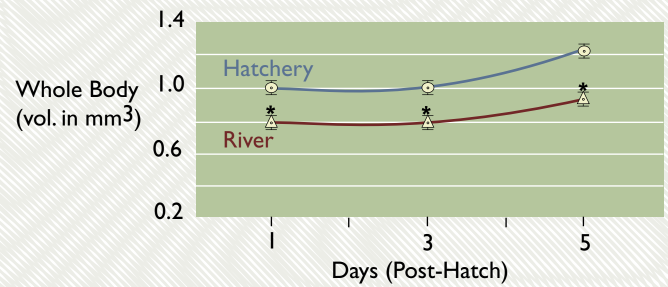
Contacts: Mark Marvin-DiPasquale, U.S. Geological Survey, mmarvin@usgs.gov
Charlie Alpers, U.S. Geological Survey, cnalpers@usgs.gov



Reservoirs: Englebright Lake (n = 3) and Camp Far West Reservoir (n = 29). Rivers: Cosumnes R. (n = 7) and Lower Yuba R. (n = 6). Streams: Alder Cr. (n = 4) and Willow Cr. (n = 6). Central Delta region: Frank's Tract (n = 6). Open-water Estuary: San Pablo Bay (n = 3). Estuarine wetlands (saltmarsh) sites included mudflats, tidal sloughs, and emergent marsh sites: lower Napa River (n = 3), Steven's Creek Marsh in South San Francisco Bay (n = 6), Suisun Marsh (n = 4), and San Pablo Bay (n = 3). This data summary representing multiple projects, was compiled by Dr. M. Marvin-DiPasquale (USGS, Menlo Park, CA), and was originally presented in the following forums and publications (Alpers et al., 2003, 2004a, 2004b; Kieu 2004; Marvin-DiPasquale et al., 2003; Marvin-DiPasquale, 2004).

Effects on Young Striped Bass

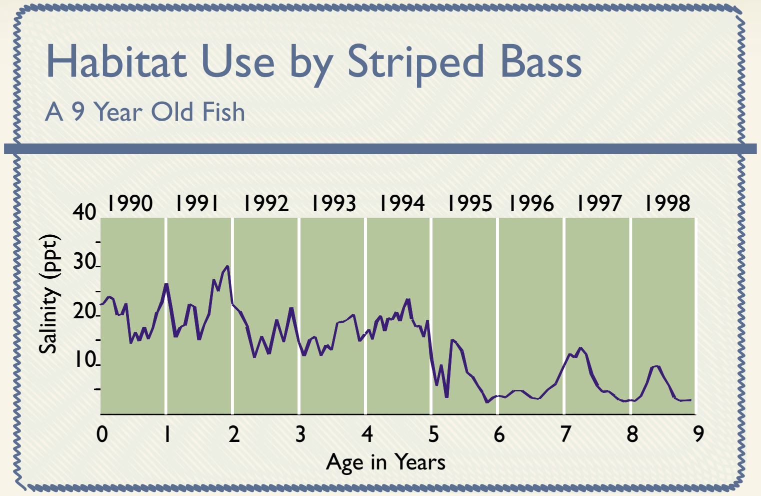
Whole Body Growth in Larvae

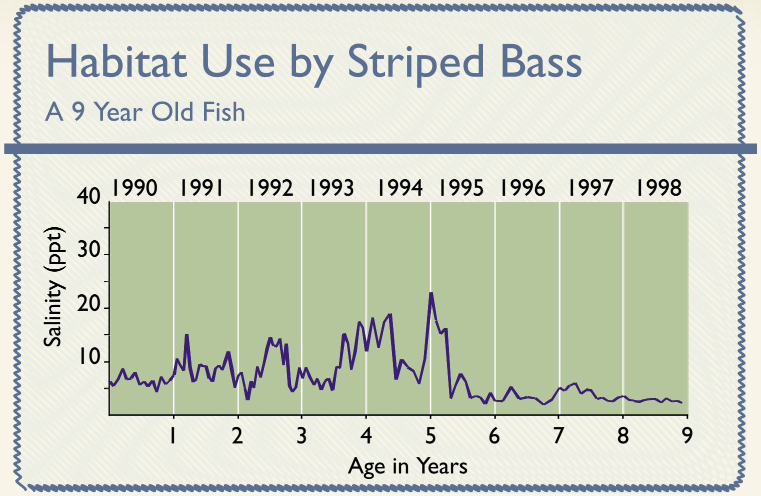


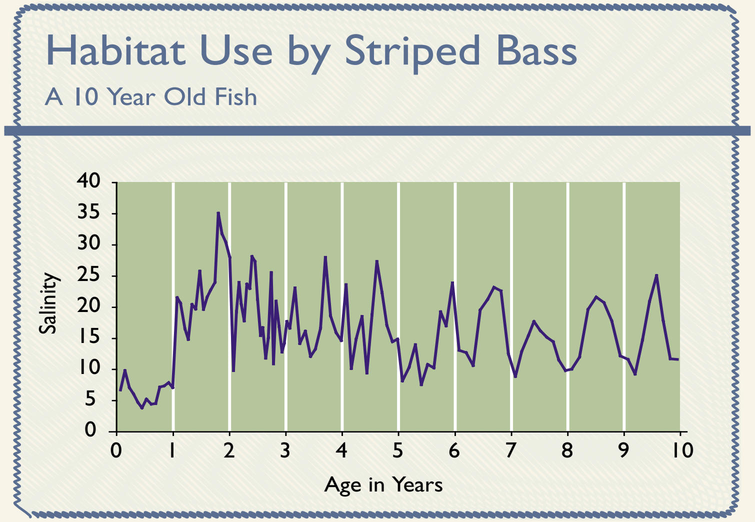
Apparent effects of pollutants on striped bass larvae. Dr. David Ostrach of U.C. Davis recently completed a multifaceted investigation of pollutant accumulation and effects in striped bass. The study compared eggs and larvae from striped bass reared in a hatchery with others caught in the Sacramento River. In similar studies in other ecosystems, larvae from the wild are usually healthier than larvae from hatcheries. In this study, eggs of River fish had significantly higher concentrations of many pollutants, including PCBs, PBDEs, and chlorinated pesticides. Under identical rearing conditions in the lab, the **larvae from the River were of poorer quality and exhibited developmental alterations (including reduced growth, more rapid yolk sac depletion, reduced brain growth, and altered liver development) that would result in reduced survival in the field.** Differences in whole body growth are illustrated above.

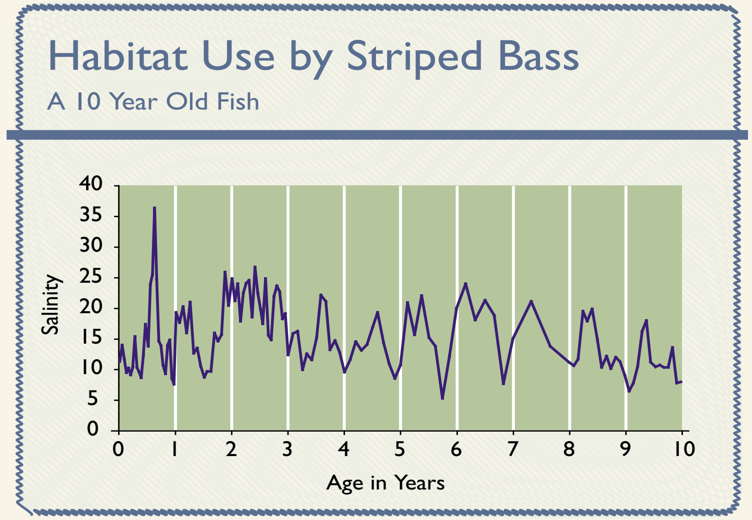
Striped bass are an important indicator species for both organic pollutants, as examined in this study, and mercury. However, striped bass have long been known to move throughout the Estuary (including freshwater, estuarine, and ocean waters) and this has been suspected of influencing their pollutant concentrations and interfering with interpretation of such data. As part of this research, Dr. Ostrach used a technique that measures the elemental composition of striped bass otoliths (ear bones) to reveal the salinity of their habitat over their lifespan. The otoliths consist of layers that are deposited every year, similar to tree rings. These analyses show that the striped bass individuals vary widely in their migration patterns, using freshwater (0 –5 ppt), estuarine (5 – 25 ppt), and saline (25 – 35 ppt) environments to varying degrees. The salinities experienced by four 9 – 10 year old bass are shown below. **This technique provides a tool that can help explain pollutant concentrations observed in this important indicator species.**

Contact: David Ostrach, U.C. Davis, djostrach@ucdavis.edu









Pyrethroid insecticides are a continuing and possibly increasing concern. Based on the overall mass of pyrethroids used, there is an indication of gradually declining use in California agriculture throughout the 1990s, with a minimum value in 1999, and a 25% increase in the past few years (top). However, this trend does not account for the shift towards more recently developed compounds which are much more toxic. From 1993 to 2002, the number of pyrethroids used in California agriculture doubled, from five to ten. During this period, use of permethrin, one of the most popular pyrethroids, dropped from 60% to 45% of the total. The newer compounds are up to 20 times more toxic than permethrin. In order to account for the toxicity differences, the use of all pyrethroids was expressed in terms of permethrin equivalents, based on their relative toxicities (bottom). For example, application of 1 kg of cypermethrin can be considered equivalent, in terms of aquatic toxicity, to application of 18 kg permethrin. After accounting for toxicity differences among pyrethroids, use patterns indicate a 58% increase in application of permethrin toxicity equivalents between 2001 and 2002. It is too soon to determine whether this increase signifies a real trend. Only a very small fraction of this toxicity-adjusted use is in fact permethrin; most of the potential aquatic toxicity is associated with compounds that are used in lesser amounts but are far more toxic. Nonagricultural use of pyrethroids, though not shown in these figures, has also had large increases. In 2002, commercial nonagricultural use in California (231,000 kg) was five times greater than in the early 1990s, with structural pest control as the principal application. Also, the State's Pesticide Use Reporting database does not track consumer home and garden use, and in this area pyrethroids have entirely replaced organophosphates such as diazinon and chlorpyrifos, which have recently been withdrawn from the consumer market by their manufacturers. The trends in California reflect a nationwide shift that indicates an emerging need to better understand the environmental fate and aquatic toxicity of pyrethroid insecticides.

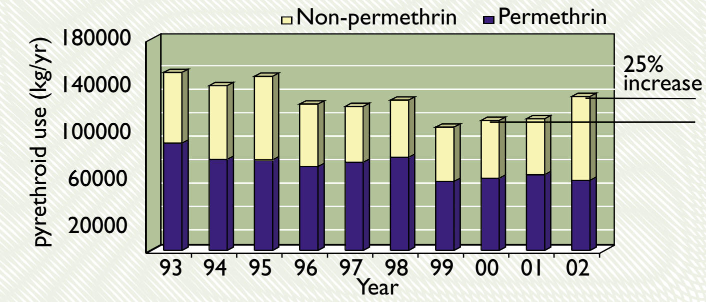
Contacts: Erin Amweg, U.C. Berkeley, erinmweg@calmail.berkeley.edu, Don Weston, U.C. Berkeley, dweston@berkeley.edu

Data Source: California Department of Pesticide Regulation, Pesticide Use Reporting System

Reference for further information: Solomon et al. (2001)

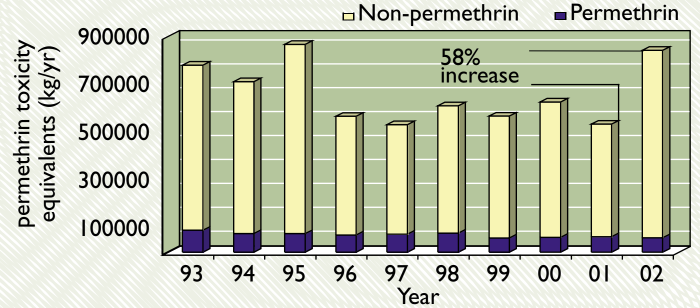
Pyrethroid Use in California Agriculture

Kilograms of Active Ingredient

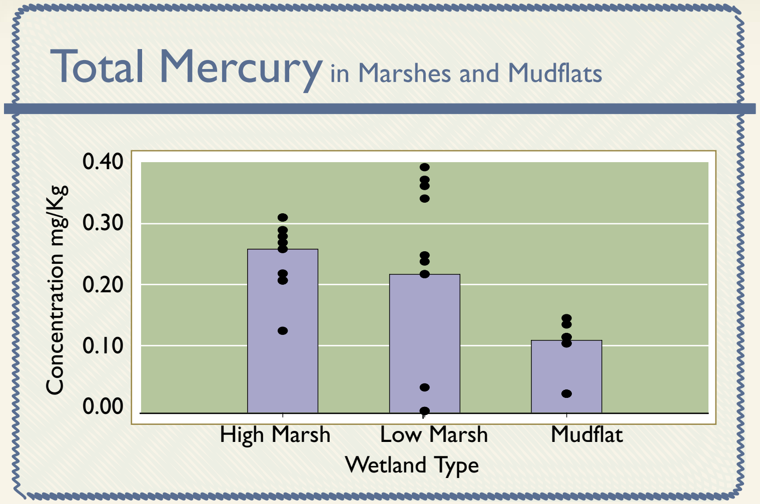


Pyrethroid Use in California Agriculture

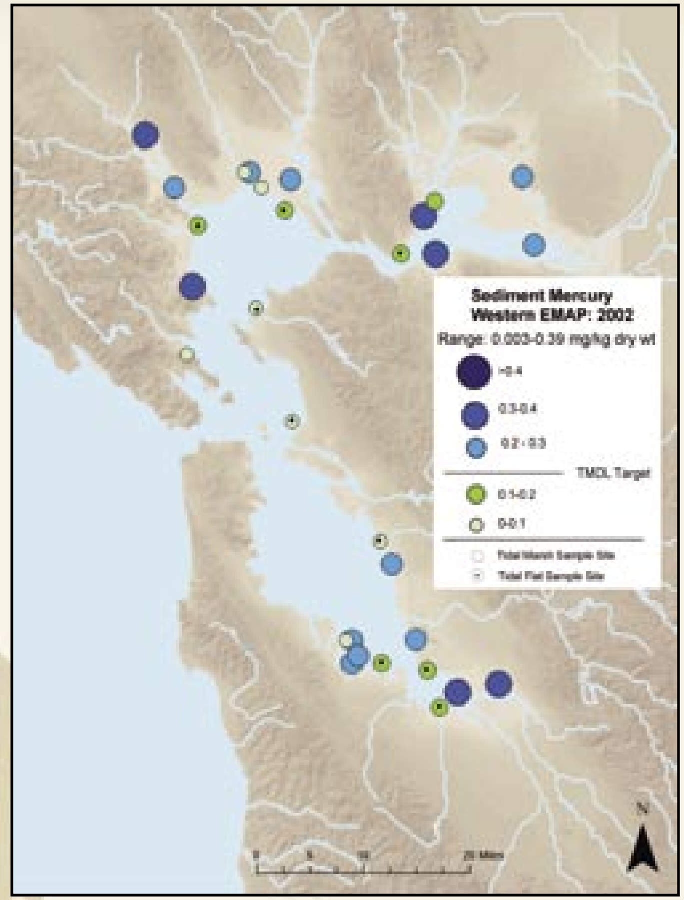
Adjusted for Relative Toxicity



Mercury in Tidal Marshes and Mud Flats. Mercury concentrations in tidal marshes are a particular concern due to the high potential for production of methylmercury in these environments (see pages 21 and 72) and potential effects on sensitive species such as the California clapper rail. Mercury mining in local watersheds, hydraulic gold mining in the Sierra Nevada, and other past activities have left a legacy of sediment contamination in Bay marshes, mudflats, and bottom sediments. While bottom sediments have been studied relatively thoroughly, little information is presently available on contaminants in tidal marshes and mudflats. SFEI surveyed intertidal contaminants, benthos, and vegetation as part of the Bay Area EMAP Intensification Project of 2002 (Collins et al. 2005). Samples were taken from mud flats, low marsh, and high marsh using a spatially randomized sampling design. Many marsh sites exceeded the 0.2 mg/kg TMDL target for mercury in sediment (see Figures). This is not surprising, given that tidal marshes act as filters that retain most materials they receive, either via tidal inundation or by aerial deposition. More of the low marsh sites had concentrations above the TMDL target. This pattern suggests that the tides are an important source of marsh mercury, since tidal inundation is more variable and less frequent across high marsh. Mercury concentrations for all mud flat sites were below the TMDL target. This could reflect erosion and dilution by rain at low tide, and the remixing of mud flat sediments from many sources. Mercury concentrations were greatest near the mouth of the Guadalupe River, where mercury-bearing sediments from the New Almaden mine enter the far South Bay. This suggests that local watersheds are important sources of sediment for mud flats and marshes.

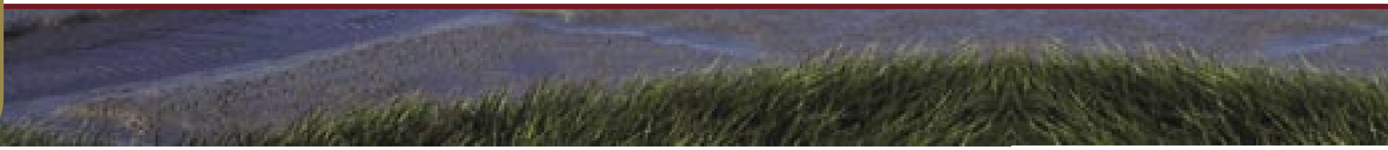


Bars show medians, points show individual measurements

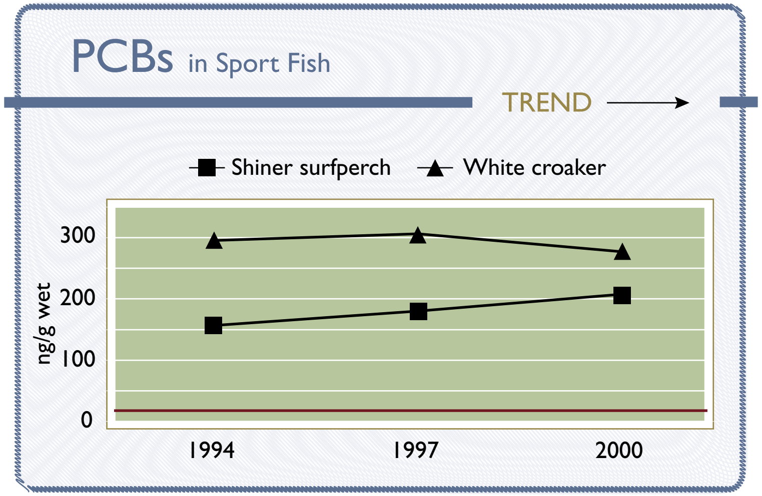


Contacts: Josh Collins, San Francisco Estuary Institute, josh@sfei.org; Cristina Grosso, San Francisco Estuary Institute, cristina@sfei.org

Water Quality Trends at a Glance

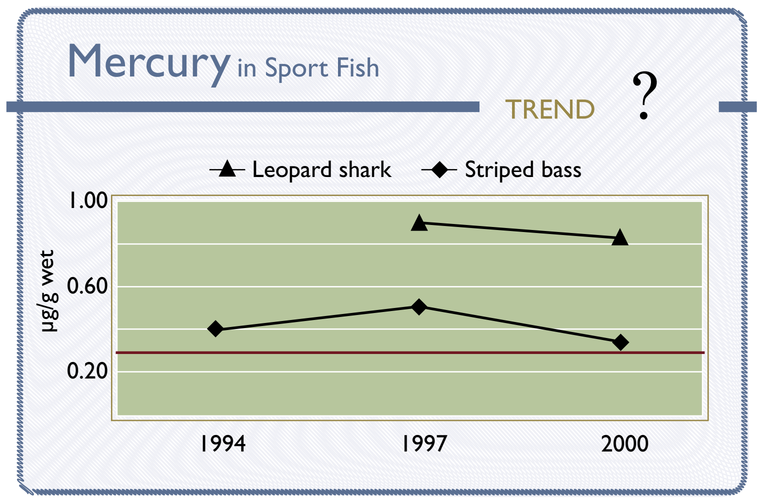


Shiner surfperch and white croaker are sport fish species that accumulate high concentrations of PCBs and are consequently important indicators of PCB impairment. Concentrations have not changed significantly since monitoring began in 1994. Red line indicates threshold for human health concern (20 ng/g).



Baywide medians. Data from the RMP and Fairey et al. (1997). Contact: Jennifer Hunt, SFEI (jhunt@sfei.org).

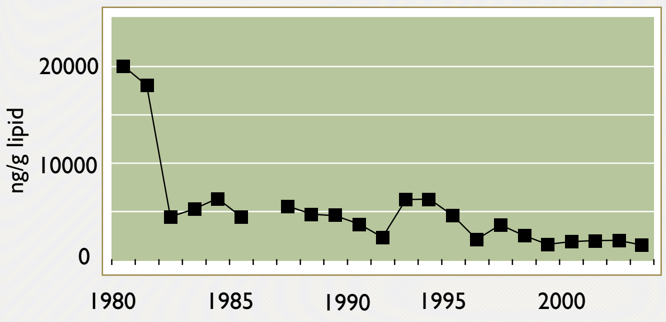
Leopard shark and striped bass are the two species that accumulate the highest concentrations of mercury and are therefore important indicators of mercury impairment. Mercury concentrations have shown some variation, but no clear long-term trend. RMP fish monitoring began in 1997. Red line indicates threshold for human health concern (0.3 ug/g).



Baywide medians. Leopard shark: 90-105 cm. Striped bass: 45-59 cm. Data from the RMP and Fairey et al. (1997). Contact: Jennifer Hunt, SFEI (jhunt@sfei.org).

PCBs in Mussels

TREND →

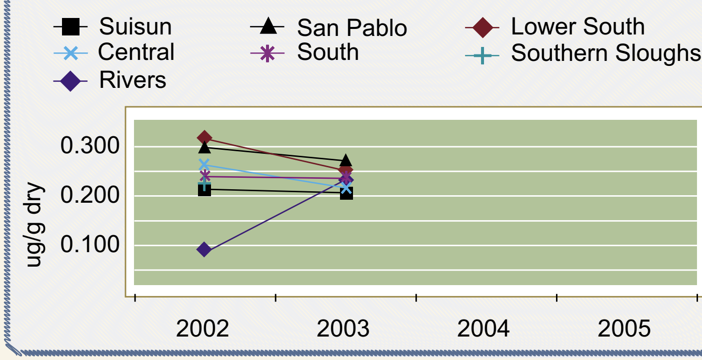


Points represent single analyses of composite samples collected in summer. Data from the State Mussel Watch Program (1980-1992) and RMP (1993-present). Contact: Jennifer Hunt, SFEI (jhunt@sfei.org).

Monitoring of mussels in the Bay provides the best available long-term record of trends in PCBs and other organic contaminants. Data shown are for one location (Yerba Buena Island) with the best time series. A ban on new uses in 1979 resulted in a dramatic decline in the early 1980s. However, since 1982, concentrations have declined slowly.

Total Mercury in Sediment

TREND →

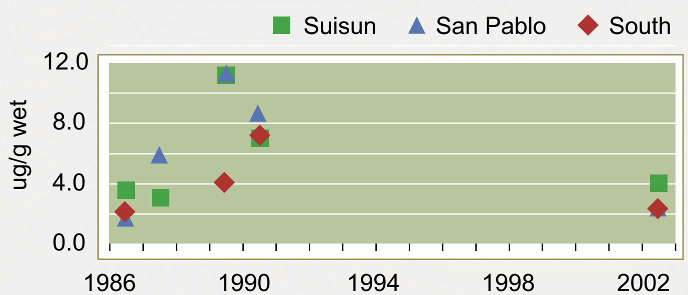


Concentrations for the Rivers were ND in 2002 – point indicates the MDL of 0.09 ug/g. Contact: Sarah Lowe, SFEI (sarahl@sfei.org).

The mercury TMDL established a target of 0.2 parts per million (ug/g dry) for mercury in sediment. In 2002 the RMP began sampling in a manner that yields representative average concentrations for each Bay segment for comparison to the target.

Selenium in Diving Ducks

TREND ?

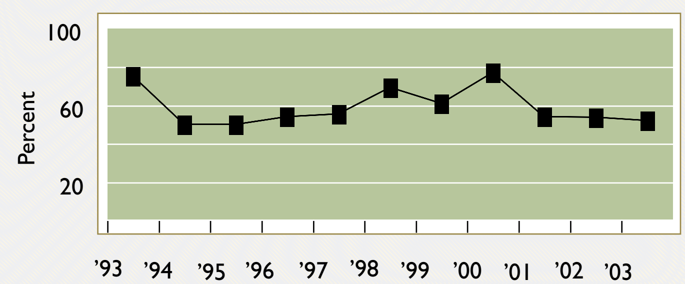


Concentrations in breast muscle. Each recent point represents a mean of 10 birds. Earlier data from the Selenium Verification Study (White et al. 1989). Contact: Jennifer Hunt, SFEI (jhunt@sfei.org).

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 of impaired waterbodies (see page 83). Concentrations measured by the RMP in 2002 were low relative to earlier measurements, but variability from year to year has been high.

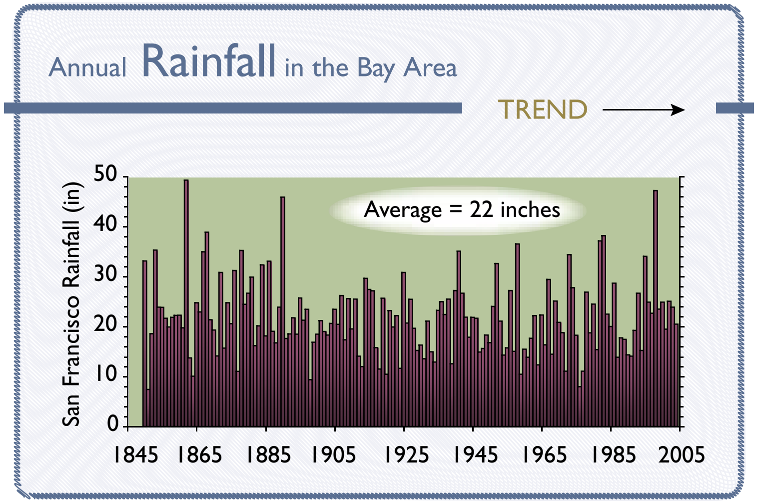
Percent Toxic Sediment Samples

TREND →



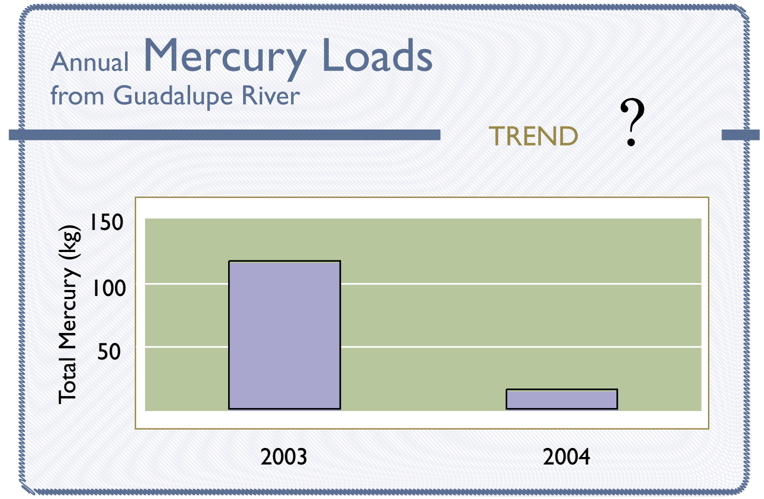
Sediment samples are tested using amphipods and mussel larvae, Contact: Sarah Lowe, SFEI (sarahl@sfei.org).

The frequent occurrence of toxic sediment samples in the Estuary is a major concern. In every year since sampling began in 1993, 50% or more of sediment samples have been determined to be toxic to one or more test species.



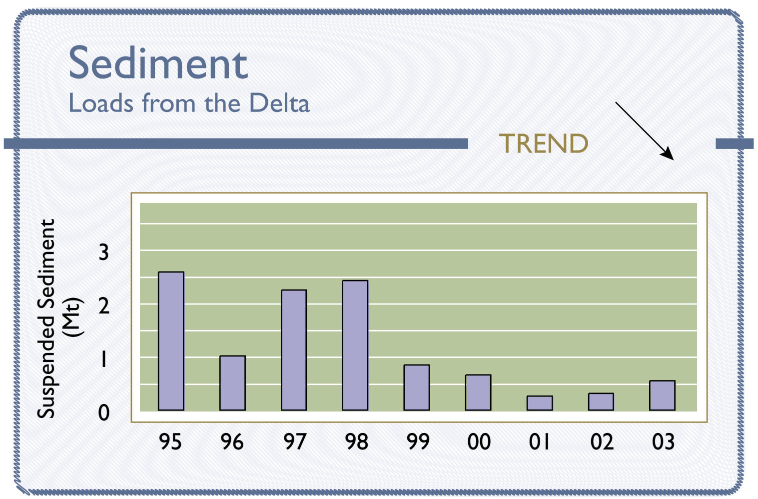
Annual rainfall measured at San Francisco. Source: Golden Gate Weather Services and Western Regional Climate Center.

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



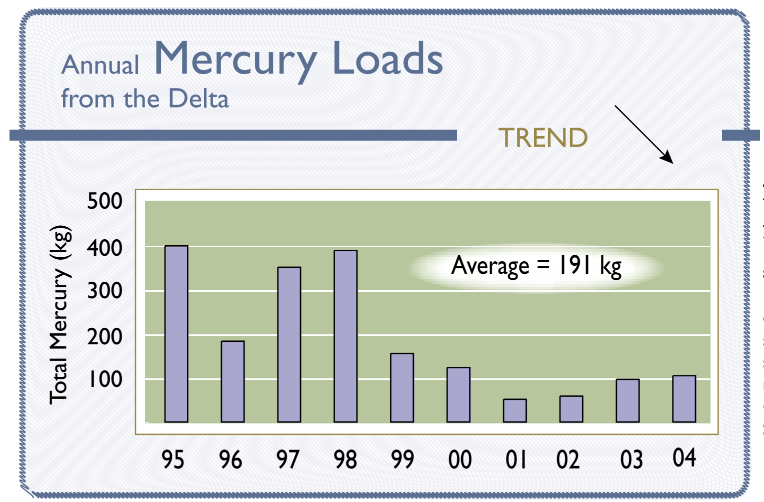
Total loads for each water year (Oct 1 – Sep 30). Contact: Lester McKee, SFEI (lester@sfei.org).

The Guadalupe River is a significant pathway for transport of mercury and other pollutants into the Bay, and the first small tributary to the Bay selected for a rigorous evaluation of loads. Loads fluctuate from year to year due to variation in rainfall and water flow from the watershed. Data from the Clean Estuary Partnership and the RMP.



Total loads for each water year (Oct 1 – Sep 30). Loads from 2002 – 2004 are based on field data. Loads for earlier years are estimated from relationships observed between suspended sediment and flow in 2002 – 2004. Data from the RMP and USGS. Contact: Lester McKee, SFEI (lester@sfei.org).

Sediment inputs from the Delta are one of the main sources of sediment supply to the Bay. Sediment inputs have diminished in recent years due to depletion of hydraulic mining debris, trapping in reservoirs, and other factors. A declining supply of sediment affects the sediment budget (see article on page 58), possibly leading to increased erosion of contaminated sediment from the Bay floor or longer periods of time needed for establishment of restored wetlands.

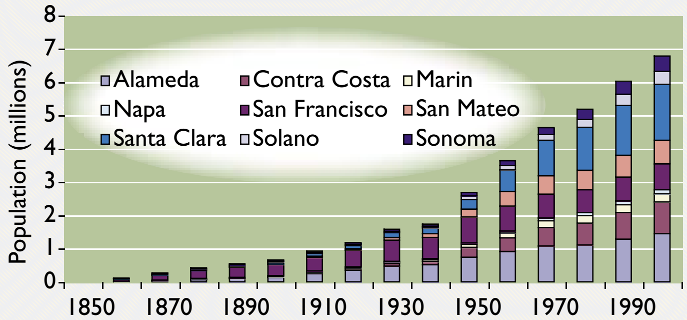


Total loads for each water year (Oct 1 – Sep 30). Loads from 2002 – 2004 are based on field data. Loads for earlier years are estimated from relationships observed between suspended sediment and mercury in 2002 – 2004. Contact: Lester McKee, SFEI (lester@sfei.org).

Delta outflow carries significant loads of mercury and other pollutants from the Central Valley watershed into the Bay. A RMP study has allowed estimation of loads from 1995 to present.

Bay Area Population

TREND ↗

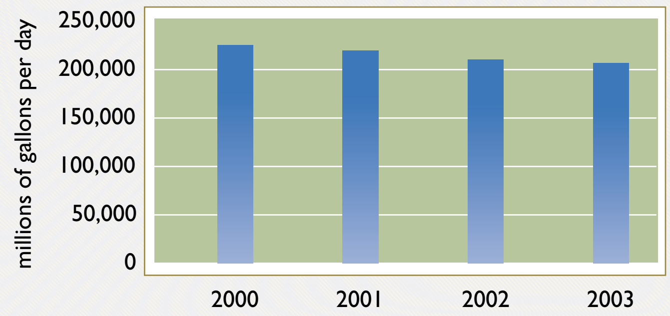


Data from the Association of Bay Area Governments. Contact: Lester McKee, SFEI (lester@sfei.org).

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

Annual Average Flow of Municipal Wastewater Effluent

TREND ↘

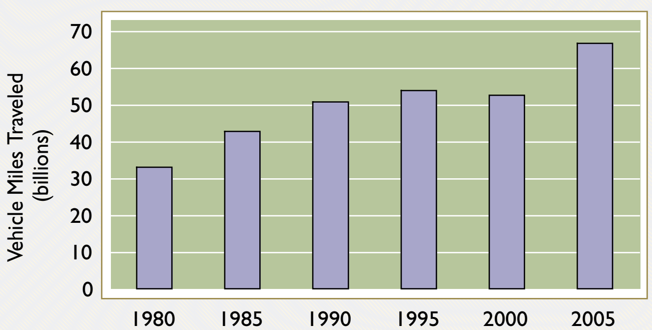


Data from the Regional Water Board. Contact: Meg Sedlak, SFEI (meg@sfei.org).

Municipal wastewater is one of the pathways for pollutant input into the Bay. In 2003, 39 publicly-owned treatment works (POTWs) discharged an average of 207,000 million gallons of effluent per day.

Vehicle miles traveled

TREND ↗

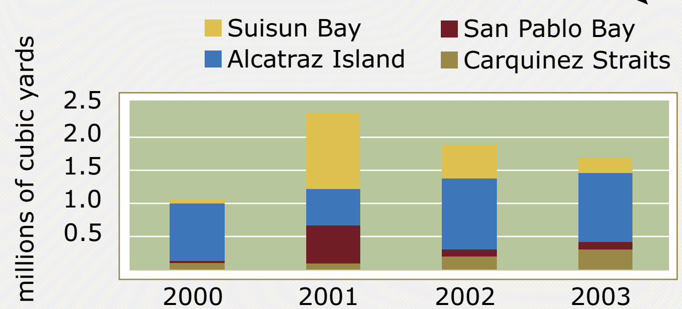


Data from Caltrans (2002). Contact: Lester McKee, SFEI (lester@sfei.org).

Automobiles are sources of PAHs, copper, mercury, and many other pollutants. Automobile use has doubled in the region since 1980. Cleaner-burning engines have reduced the magnitude of pollutant emissions.

In-Bay Disposal of Dredged Material

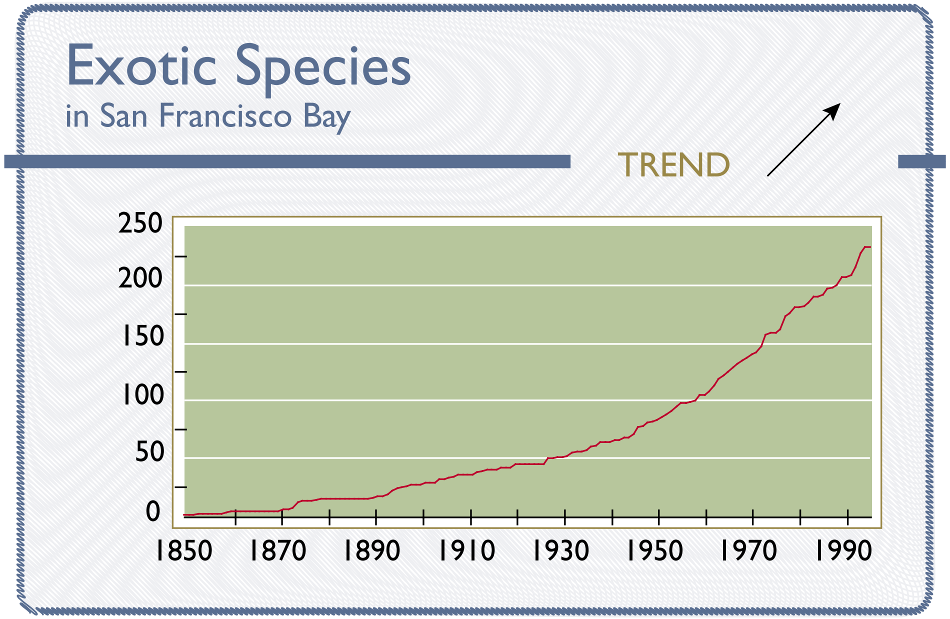
TREND ↘



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

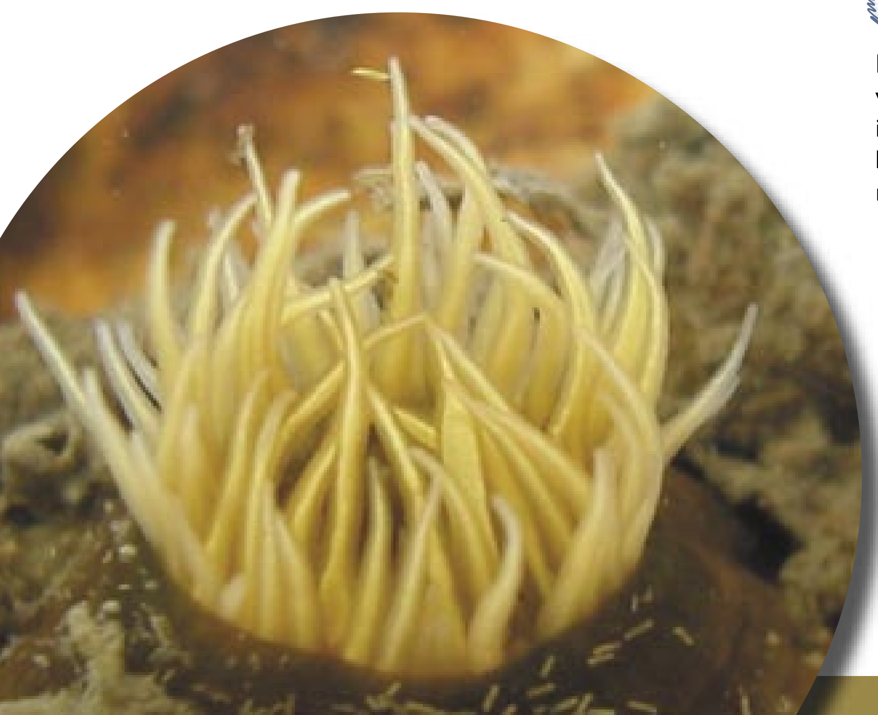
Annual Volume of Dredged Material Disposed of in the Bay. Dredged material disposal is one of the pathways for pollutant input into the Bay. In 2003, 1.69 million cubic yards of dredged material were disposed of at the four disposal sites in the Bay. Other dredged material was disposed of in the ocean and used in restoration projects in wetland and upland areas.

San Francisco Bay is considered one of the most highly invaded estuaries in the world, and the ecological impacts of exotic species have been immense



From Cohen and Carlton (1998). Contact: Andy Cohen, SFEI (acohen@sfei.org).

Exotic species in the Bay are included on the 303(d) list of impaired waterbodies (see page 83). San Francisco Bay is considered one of the most highly invaded estuaries in the world, and the ecological impacts of exotic species have been immense. The number of exotic species in the Bay has increased sharply in recent decades.



Diadumene lineata

Busycotypus canaliculatus

The big picture of water quality in the Estuary

Feature Articles

Polybrominated Diphenyl Ether (PBDE) Flame Retardants in San Francisco Bay

Daniel Oros[1] (daniel@sfei.org), Karen Taberski[2], and Thomas A. McDonald[3]

[1]San Francisco Estuary Institute, Oakland, CA [2]San Francisco Bay Regional Water Quality Control Board, Oakland, CA
[3]Office of Environmental Health Hazard Assessment, Oakland, CA

Key Points

- Concentrations of PBDEs in humans and wildlife in the Bay Area are among the highest that have been reported in the world
- Over the past 20 years, PBDE levels in many North American wildlife species have doubled every 4-6 years, and levels in humans have also risen dramatically
- California passed a law banning the use of the two most environmentally mobile commercial PBDE mixtures, Penta-BDE and Octa-BDE, by June 1, 2006, but a third mixture, Deca-BDE, is exempted from this ban
- PBDEs are currently on the Water Board's Section 303(d) "watch" list to encourage the collection of more information to answer management questions

A Global PBDE Hotspot?

The San Francisco Bay Area appears to be a global hotspot of polybrominated diphenyl ether (PBDE) contamination. These flame retardant compounds potentially present a pollutant problem similar to the PCBs. The evidence suggests that PBDEs will become the next legacy pollutant in the Bay.

Disclaimer: The views expressed by Dr. McDonald do not necessarily represent those of the Office of Environmental Health Hazard Assessment, the California Environmental Protection Agency or the State of California.

Recent studies conducted in the Bay Area have identified the polybrominated diphenyl ether flame retardants in humans (She et al., 2002; Petreas et al., 2003), harbor seals (She et al., 2002), fish (Holden et al., 2003), tern eggs (She et al., 2004), municipal wastewater treatment plant effluents (North, 2004), and Bay water, surface sediments, and bivalves (Oros and David, 2002; Oros et al., 2005). Tern egg samples from the Bay are reported as having the highest levels of PBDEs (63 mg/kg lipid wt) ever reported for wildlife (She et al., 2004), while Bay Area women have some of the highest levels reported in humans (She et al., 2002). Due to the growing body of evidence showing PBDEs in humans and marine mammals on the increase worldwide, the RMP began monitoring for PBDEs in the Bay water, surface sediments, and bivalves in 2002.

The PBDEs are a family of chemicals (known as "congeners") with varying numbers of bromine atoms. PBDEs have been in use for over 30 years in the form of three commercial mixtures identified as Penta-BDE, Octa-BDE, and Deca-BDE. Their principal use is as flame retardants in manufactured products such as polymers, resins, electronic devices (e.g., TVs, computers, hair dryers, and coffee makers), building materials, textiles, and polyurethane foam padding used in furniture and carpets. The Penta-BDE mixture is composed primarily of five congeners that include BDE-47, BDE-99, BDE-100, BDE-153, and BDE-

154 - these five congeners are the same ones found at the highest concentrations in most marine mammals and humans. The Octa-BDE mixture contains several congeners with six bromines, such as BDE-153 and BDE-154, and contains BDE-183 (seven bromines) as the major congener. The Deca-BDE mixture is composed primarily of the fully brominated BDE-209 (ten bromines) with small amounts of congeners with nine bromines (Darnerud et al., 2001).

In 2001, the total market demand for PBDEs in North America was 33,100 metric tons, which accounts for 49% of the world demand (BSEF, 2003). Deca-BDE was the most commonly used commercial mixture (24,500 metric tons) in North America followed by lesser amounts of Penta-BDE (7,100 metric tons) and Octa-BDE (1,500 metric tons). California has the most stringent flame retardant standards in the U.S., hence it is presumed to have the highest level of PBDE use.

As a result of their widespread use in consumer products, PBDEs have found their way into the environment. Various transport pathways to aquatic ecosystems have been identified including atmospheric transport, industrial and municipal wastewater effluent discharges, landfill leaching, and stormwater runoff. In the environment, PBDEs are known to persist, bioaccumulate in human and animal fat, and biomagnify up the food web resulting in the highest concentrations in top predators such as marine mammals, birds, and humans (Alaee et al., 1999; She et al., 2002, 2004; Ikonomou et al., 2002).

In Europe and in North America, studies have shown dramatic increasing trends in PBDE levels in humans and the environment over the past two decades. For instance, the concentrations of several PBDE congeners in breast milk of nursing Swedish women doubled every 5 years from 1972 to 1997 (Meironyté et al., 1999), while in Norway, human serum PBDE concentrations doubled every 8 years from 1977 to 1999 (Thomsen et al., 2002). In Sweden, guillemot egg PBDE concentrations doubled every 5.8 years from 1970 to 1989 (Sellström et al., 1993). In North America, PBDE concentrations in humans and the environment have generally doubled every 4-6 years (Hites, 2004). In the Great Lakes, PBDE concentrations in herring gull eggs doubled every 3.4 years from 1981 to 2000 (Norstrom et al., 2002). In San Francisco Bay, harbor seal PBDE concentrations doubled every 1.8 years from 1989 to 1998 (She et al., 2002), while in two fish species (halibut and striped bass) collected from San Pablo Bay PBDE concentrations doubled in 7 years from 1997 to 2003 (Holden et al., 2003).

The toxicity of PBDEs is not entirely understood. The most sensitive health endpoints for the PBDEs appear to be developmental effects harming the developing brain and reproductive organs (Darnerud et al., 2001; McDonald, 2002, 2004). PBDE exposure disrupted the thyroid and estrogen hormone systems in rodents (McDonald, 2002, 2004), which may be mechanisms underlying the developmental effects observed. Exposure of rats or mice, either during gestation or soon after birth, resulted in permanent changes in behavior, learning, and memory. Early life exposures also resulted in permanent changes to the reproductive organs, such as reduced sperm count and alterations to the ovary cell structure (Darnerud et al., 2001; McDonald, 2004).

PBDEs are Widely Distributed in the Bay

Water. PBDEs are widely distributed throughout the Bay water column. The total PBDE (sum of all PBDE congeners) concentrations in the RMP 2002 water samples ranged from 3 to 513 pg/L (parts per quadrillion), with the highest concentrations found in the Lower South Bay (range 103-513 pg/L) region (**Figure 1**) (SFEI, 2004). The Penta-BDE, Octa-BDE,

and Deca-BDE commercial mixtures are all present in the water column. PBDEs are mostly adsorbed to suspended particulate matter in the water column with >78% of PBDEs being bound.

Sediments. In the RMP 2002 Bay sediment samples, PBDE concentrations ranged from below detection limits to 212 ng/g (parts per billion) (**Figure 2**) (SFEI, 2004). The highest concentration was found at a South Bay station (212 ng/g), which was up to 100 times higher than other stations. Both the Penta-BDE and Octa-BDE mixtures were found in sediments, but Deca-BDE (BDE-209) was below its detection limit (<1.5 ng/g).

PBDEs are widely distributed in Bay water, surface sediments, and bivalves

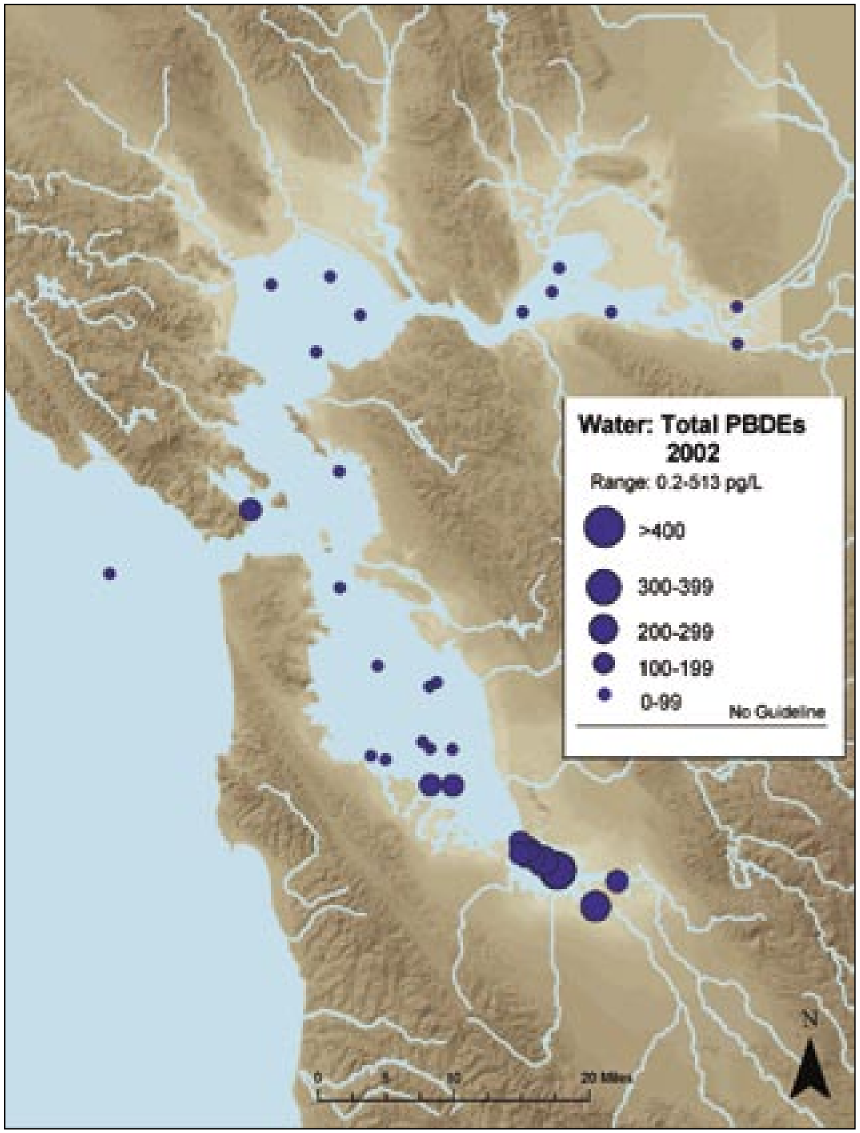


Figure 1. PBDEs, a class of flame retardants that were practically unheard of ten years ago, are now found in waters throughout the Estuary. The highest PBDE concentrations in 2002 were measured in waters in the Lower South Bay. Elsewhere, they were present but uniformly low relative to the South Bay.

Bivalves. Bivalves are excellent sentinels for determining contaminant bioavailability in the water column and tracking year-to-year trends. In the 2003 RMP bivalve samples, PBDE concentrations ranged from 12 to 44 ng/g in transplanted mussels, and from 96 to 98 ng/g in resident clams (**Figure 3**). Only three PBDE congeners were detected in bivalves, BDE-47, BDE-99, and BDE-100, which are the most bioaccumulative congeners from the Penta-BDE mixture. Octa-BDE and Deca-BDE mixtures were not detected, which could be due to their large molecular size and limited bioavailability. The PBDE concentrations in resident clams from the Sacramento and San Joaquin River stations were much higher than those found in transplanted mussels, possibly due to their longer exposure period (transplants are in place for only 90 days).

In summary, the RMP monitoring results show that PBDEs are widely distributed in Bay water, surface sediments, and bivalves. In water, the highest concentrations were found at a Lower South Bay station, while in surface sediments the highest concentration was found at a South Bay station. In bivalves, the highest PBDE concentrations were found in resident clams collected from the Sacramento and San Joaquin River stations. The Penta-BDE, Octa-BDE, and Deca-BDE commercial mixtures were each found in the Bay.

Limited Information Available on PBDE Sources

Information on sources of PBDEs to the Bay is presently very limited. Municipal wastewater is one source that has received some attention. A recent study conducted at the Regional Water Quality Control Plant, a sewage treatment facility in Palo Alto, CA that treats 25 million gallons per day, showed that

BDE-47, BDE-99, and BDE-209 were the major congeners in effluent that is discharged into the Bay at a total PBDE loading rate of 0.9 kg/yr (North, 2004). Assuming that this loading rate applies to all wastewater treatment plants that discharge into the Bay, the estimated level of total PBDE loading from discharged effluents would be approximately 23 kg/yr. In comparison to the estimated current level of PCB loading to the Bay from wastewater treatment plants 2.3 kg/yr (CRWQCB, 2004), the estimated level of sum of PBDE loading (23 kg/yr) is about ten times higher. This could represent a significant amount of PBDE loading to the Bay from these sources.

Other possible sources and transport pathways which could be significant and have yet to be evaluated for PBDE loading contributions to the Bay include atmospheric deposition, industrial effluent discharges, landfill leaching, storm drains, and small and large tributaries. Determining the loading contribution from each of these pathways would allow management efforts to target the most important sources and transport pathways to reduce loading. A joint study of the Clean Estuary Partnership (CEP) and RMP in 2005 will provide preliminary information on loads from some of these pathways.

Human Exposure and Health Risks

Concern for possible human health effects of PBDEs is focused on a small percentage of the population with unusually high concentrations. The average levels of PBDEs in the tissues of women from the U.S. was about 90 ng/g (on a lipid weight basis), but varied widely among individuals, ranging from roughly 1 to greater than 1000 ng/g (Hites, 2004). In the U.S., 12 out of 191 individual U.S. women (6%) tested for PBDEs in serum, breastmilk, or adipose tissue samples, had levels that were greater than 300 ng/g (McDonald, 2004, 2005). This means that a large number of U.S. women, and presumably men, could potentially have high PBDE body burdens.

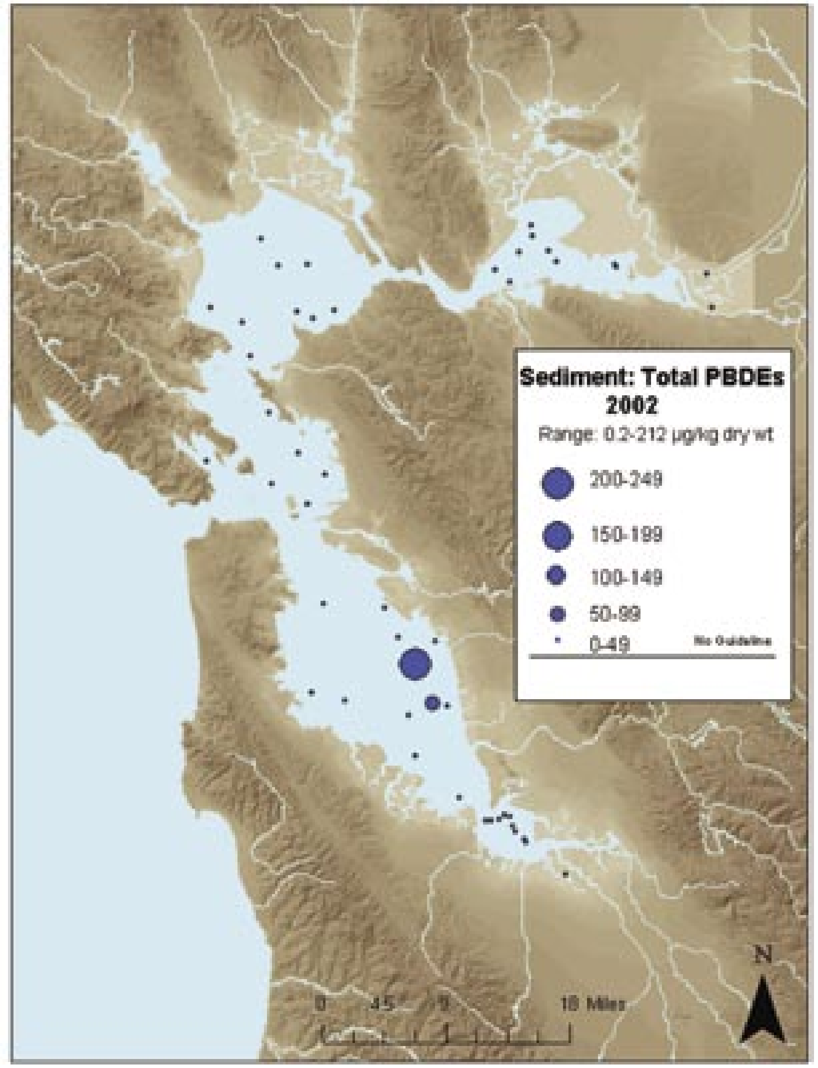


Figure 2. PBDEs are building up in Bay sediment, possibly creating a problem that will persist for decades. Once persistent pollutants become mixed into Bay sediment, they are trapped in the ecosystem until they degrade, volatilize, or slowly are flushed out through the Golden Gate. Sediment PBDE concentrations in 2002 ranged from below detection limits to 212 ng/g. The highest concentration was found at a South Bay station, which was much higher than the other stations. These sediment PBDE data were generated using a relatively insensitive method and should be considered preliminary estimates.

The primary pathways of human exposure to PBDEs are from PBDE-containing foods and from direct indoor exposures to PBDEs in house dusts, surfaces, and indoor air. For some individuals, it appears that diet is the primary pathway of exposure, but for others air exposure pathways may predominate (Wilford et al., 2004). In addition to exposure, there are many other factors that add to the wide range of PBDE levels observed in humans. These factors include inter-individual differences in uptake, metabolism and excretion, dietary factors, body fat content, and factors affecting the mobilization of fat stores, such as dieting, fasting, breastfeeding, and exercise.

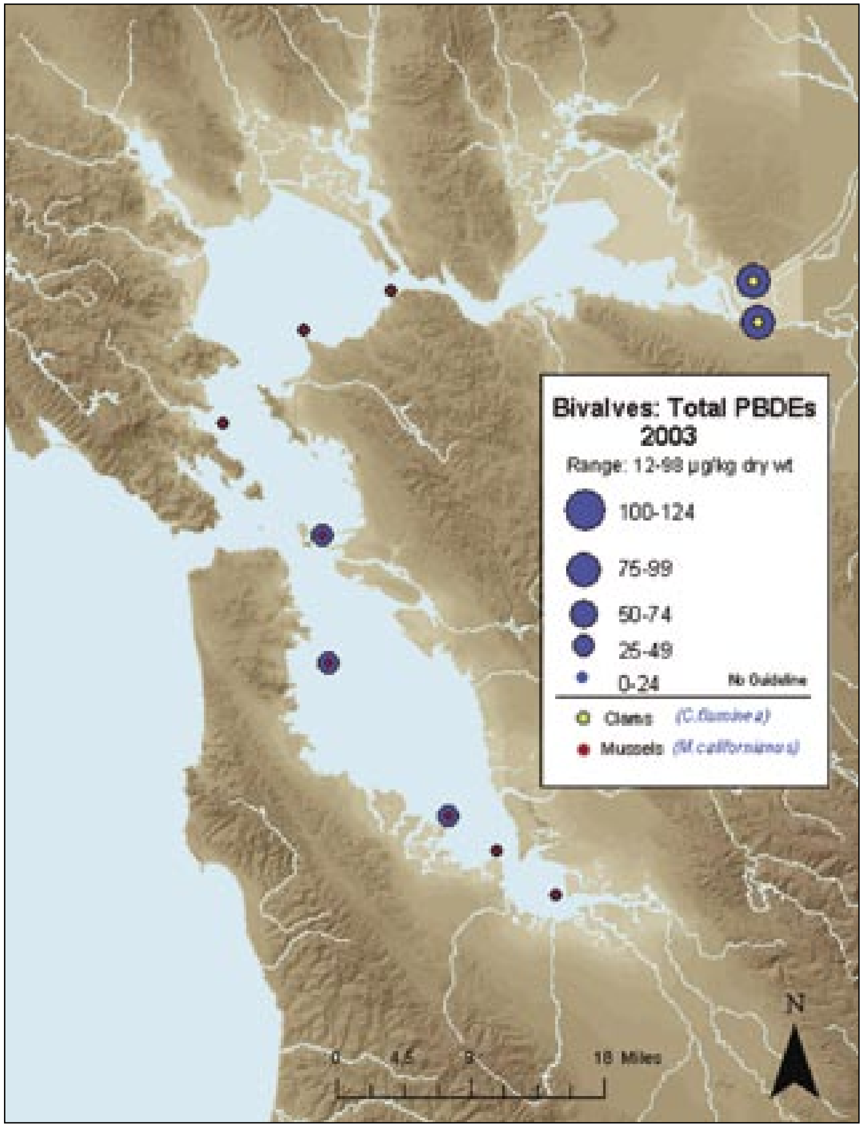


Figure 3. PBDEs are currently on the 303(d) watch list due to increasing concentrations in the Estuary and concerns about their possible effects at the top of the food web. The California legislature banned the use of the two most environmentally mobile commercial PBDE mixtures, Penta-BDE and Octa-BDE, by June 1, 2006. Tracking the trends in these chemicals is extremely important to determine what effect, if any, the ban will have and if further management actions are necessary. PBDE concentrations in bivalves are one of the tools being used by the RMP to track long-term trends and spatial patterns in the Bay. PBDE measurements in bivalves in 2003 found highest concentrations in clams at the eastern boundary of Suisun Bay.

The toxic endpoints likely to be the most sensitive for the PBDEs are thyroid and estrogen hormone disruption, neurobehavorial toxicity, other developmental effects, and possibly cancer. Sensitive populations include pregnant women, developing fetuses, and infants. Recent animal studies have shown that exposure to PBDEs altered expression of estrogen-responsive genes in several organs (Lichtensteiger et al., 2004), which was not expected based upon low estrogenic activity in studies of cell cultures (Meerts et al., 2001). More studies are needed to determine if low-dose exposures to PBDEs have estrogenic activity in humans or other species.

The potential health effects of PBDEs to humans have been examined by comparing tissue concentrations in humans to the tissue concentrations in rodents associated with developmental neurotoxicity and reproductive effects in rodents (McDonald, 2004; 2005). For most individuals, the body burdens have not reached levels associated with developmental effects in rodents. However, for some individuals, for example, those with body burdens that were higher than 300 ng/g, the margin of safety appears to be fairly low (McDonald, 2004; 2005). For example, tissue levels in rodents causing behavorial changes were only about 5 to 100 times higher than levels in humans with PBDE levels greater than 300 ng/g, depending on the study used for comparison (McDonald, 2004).

There remain a variety of data gaps that are relevant to human PBDE exposure and health risk assessment. Current research needs to focus on why some people have such high body burdens, while levels in most individuals are relatively low. We need a better understanding of what foods contribute significantly to dietary intake of PBDEs, and how those levels might be mitigated. Also, research is needed to determine which factors contribute to indoor PBDE exposure, including the potential contribution of dermal exposures. In addition, research is needed on host factors that may affect an individual PBDE body burden (e.g., metabolic capability, body fat content, active transporters).

Concern for human health is focussed on a small percentage of the population with unusually high PBDE concentrations

Efforts to Reduce PBDE Contamination

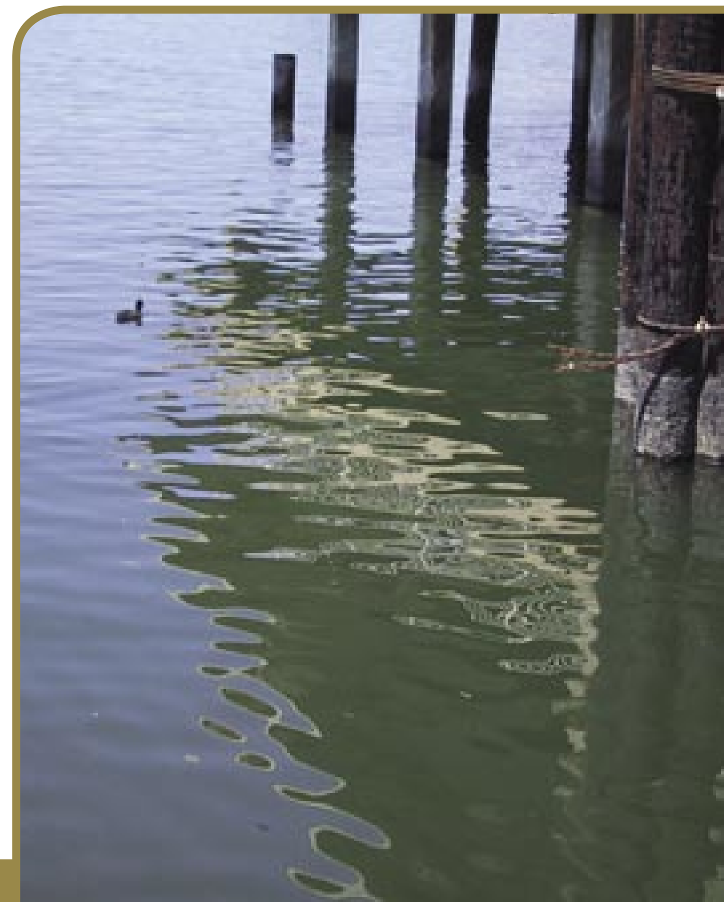
Data collected by the RMP and other efforts prompted the San Francisco Bay Regional Water Quality Control Board (Water Board) to place PBDEs on the 2002 303(d) non-regulatory "watch" list for the Bay. The purpose of this list is to encourage collection of additional data to help answer management questions. Currently, there is limited understanding of all the sources of PBDEs to the environment and fate and transport in the Bay. There is, however, evidence showing that PBDEs are increasing in the Bay food web, correlated with increases in manufacturing and use.

In Europe, the European Union enacted a ban on both Penta-BDE and Octa-BDE, the two most mobile forms of commercially used PBDE mixtures, in all products, which took effect August 15, 2004. In the U.S. the only manufacturer of Penta-BDE and Octa-BDE in the U.S., Great Lakes Chemical, agreed to voluntarily phase out production by December 31, 2004. The U.S. EPA has followed up this voluntary phase out with a proposed Significant New Use Rule, which will ensure that the manufacturing or importing of these two PBDE mixtures cannot occur after January 1, 2005. In August 2003, California became the first state in the U.S. to ban the use of Penta-BDE and Octa-BDE. The law, as amended in 2004, requires that these two PBDE mixtures be phased out of use in California by June 1, 2006. However, Penta-BDE and Octa-BDE will continue to leach into the environment for many years to come, since millions of pounds of these chemicals are currently in numerous everyday products such as furniture, automobiles, and electronic equipment. The Deca-BDE mixture was exempted from this ban. However, because it is converted to lower molecular weight congeners in the environment (Söderström et al., 2004; Stapleton et al., 2004), the Deca-BDE exemption raises questions and concerns over how it may break down into compounds that are more readily bioavailable and potentially increase PBDE concentrations in organisms in the Bay.

California became the first state in the U.S. to ban the use of Penta-BDE and Octa-BDE

Although PBDEs are detectable in the Bay at levels that are lower than those thought to cause toxicity in aquatic animals, their dramatic global increase in aquatic food webs and the possibility that they could act together with other similar chemicals in the Bay, such as PCBs, causes concern. PBDEs currently do not have water quality objectives, criteria, or guidelines. These need to be developed in order to determine if the Bay is impaired and to make informed management decisions. Due to these concerns and the lack of adequate data, an increasing number of studies are now being conducted in the U.S. to measure PBDEs in humans and the environment, assess their toxicity, and identify major sources and transport pathways. The National Toxicology Program is sponsoring studies to investigate the toxicity of PBDEs and other brominated flame retardants. The regional office of the U.S. EPA has convened pollution prevention workgroups to assess general sources and pathways of PBDEs and other brominated flame retardants. The Water Board will enlist the assistance of stakeholders to find the best way to reduce or eliminate PBDEs since there are currently no source control or pollution prevention efforts in place.

The RMP will continue its annual monitoring of PBDEs in the Bay to examine spatial distributions and temporal trends and to fill critical data gaps. Data gaps of immediate concern include the identification of major sources, transport pathways, effects thresholds on aquatic biota, biomagnification pathways through the Bay food web including humans, and the residence time of these contaminants in the Bay. A study to identify sources and develop a conceptual model is currently being funded in a coordinated effort by the RMP and Clean Estuary Partnership (CEP). This impairment assessment will contribute to a basis for informed decisions on the management of PBDEs in the Bay.



The Legacy of Organochlorine Pesticides in San Francisco Bay

Christine Werme (werme@sbcglobal.net), Jon Leatherbarrow, and Mike Connor, San Francisco Estuary Institute

Key Points

- Decades after their use was curtailed, legacy organochlorine pesticides, including DDTs, chlordanes, and dieldrin, persist in San Francisco Bay
- Continued inputs of legacy pesticides to the Bay come primarily in runoff from the Central Valley and local watersheds
- Degradation of pesticides in the sediments is the primary mechanism of removing legacy pesticides from the Bay
- DDTs and dieldrin are of some concern as contaminants in sport fish; the more likely effects of chlordanes are on animals living in the sediments
- If inputs of legacy pesticides to the Bay continue at present rates, we can anticipate only very slow declines in levels of legacy pesticides, particularly DDTs and chlordanes

From Miracle to Menace

In 1939, after testing hundreds of chemicals, a Swiss scientist named Paul Müller found one chemical compound that killed flies, aphids, beetles, and gnats. It was an organochlorine compound (a carbon-based molecule incorporating chlorine atoms), dichloro-diphenyl-trichloroethane, now known around the world as DDT. Further tests suggested that DDT was effective in very small doses, was practically non-toxic to humans, and was cheaply and easily manufactured. Soon, DDT was being used to fight disease—typhus, malaria, plague, and yellow fever—and in 1948, Dr. Müller was awarded the Nobel Prize in medicine. Farmers also discovered DDT. And similarly, other organochlorine pesticides, such as chlordanes and dieldrin, were manufactured and marketed as miracle products.

But in 1962, with the publication of marine biologist Rachael Carson's *Silent Spring*, public opinion began to change. For the first time, many people learned how DDT entered the food chain and accumulated in fatty tissues of fishes, birds, and human beings. For the first time, people heard that DDT was a probable carcinogen. For the first time, people read that the principal vector of plague, the rat flea, had developed resistance to DDT.

As early as 1963, use of DDT began to be controlled in California, and in 1972, the U.S. government banned it for all but emergency public health uses. Likewise, chlordanes and dieldrin were restricted in California in the 1970s, and their uses were ended in the United States in the 1980s (**Table 1**).

This article summarizes the key findings of a report entitled Legacy Pesticides in San Francisco Bay: Conceptual Model/Impairment Assessment prepared by SFEI for the Clean Estuary Partnership (Connor et al., 2004). The full report is available at www.sfei.org.

Until 1971, California did not require anyone to report use of DDT or the other organochlorine pesticides, so there are no records of the amounts used on fields, for mosquito control, or for other types of pest management. But DDT was the most-used pesticide in history, and nationally, more than 1 billion pounds were applied over a 30-year period.

One of the traits that so impressed Dr. Müller when he first discovered DDT's capabilities was that its toxicity persisted over time. Indeed, the organochlorine pesticide researchers found for the first time that thorough cleaning of their testing equipment was necessary to keep from ruining subsequent experiments. The trait of persistence was even greater than Dr. Müller appreciated—more than 30 years after their use was curtailed, the organochlorine pesticides persist in the water, soils, sediments, plants, and animals. That's why we refer to them as "legacy pesticides," pesticides that are no longer used but that continue to be present and cause adverse effects on the environment.

Illustration from National Geographic, 1945

Illustration from Time Magazine, 1947

The legacy pesticides include DDTs (two forms of DDT and their breakdown products), chlordanes (several insecticides, including heptachlor), and dieldrin. These legacy pesticides are considered to be threats to San Francisco Bay, because along with PCBs, mercury, and dioxins, they have been found in sport fish (such as jacksmelt, shiner surfperch, white croaker, striped bass, California halibut, leopard shark, and white sturgeon) and other Bay organisms. In 1994, because of the presence of these pollutants, the state Office of Environmental Health Hazard Assessment (OEHHA) issued an interim advisory for consuming fish caught in the Bay. The advisory recommends that adults limit their consumption of sport fish from the Bay to two meals per month.

Largely because of the OEHHA advisory, all segments of San Francisco Bay are listed as "impaired by legacy pesticides" under Section 303(d) of the federal Clean Water Act. During the past two years, the Clean Estuary Partnership has been developing Conceptual Model/Impact Assessment reports for

Table 1. Legacy pesticides

	History of Use	Toxicity
DDTs	• Used from 1939 to 1972. • Broad spectrum insecticide used on agricultural crops, for pest control, and for mosquito abatement. • Extensive use in California began around 1944. Declared a restricted material in California in 1963 and banned in the U.S. in 1972.	• Neurotoxic and a probable human carcinogen. Effects on early life stages and reproduction in wildlife.
Chlordanes	• Used from 1948 to 1988. • Originally used on agricultural crops, lawns, gardens, and as a fumigating agent. • Most uses banned in 1978, and after 1983, used only for termite control.	• Neurotoxic and a probable human carcinogen.
Dieldrin	• Used from 1948 to 1987. • Originally used on agricultural crops. • After 1974, used only for termite control.	• Neurotoxic and a probable human carcinogen.

Table 1. Legacy pesticides include DDTs, chlordanes, and dieldrin. The pesticides were widely used on farms and in homes. All are neurotoxins and probable human carcinogens.

the pollutants on the 303(d) list for San Francisco Bay. Preparing the report on legacy pesticides gave us an opportunity to synthesize available information on continuing sources of the pesticides and their fates after they reach the Bay. It also gave us an opportunity to review the most up-to-date information on the potential effects of the legacy pesticides in the Bay, including effects on the environment and on human health.

Where Do Legacy Pesticides in the Bay Come From?

When we talk of pollutants, including legacy pesticides, "in San Francisco Bay," we mean that they are in either the water column or in the "active sediment layer," (the top portion of the sediments, which interacts with the water column) (Davis et al., 2001).

Legacy pesticides enter the water column and the active sediment layer from a variety of sources: in runoff from the mostly-agricultural Central Valley; in runoff from the more urban, local watersheds; in wastewater from sewage treatment plants; in industrial effluent; as atmospheric deposition of pesticides that have been volatilized; and from resuspension of sediments that are within the Bay but buried more deeply than the active layer (**Figure 1**). These deeper sediments find their ways into the water or active sediment layer by erosion of deep deposits and through dredging and disposal of dredged material.

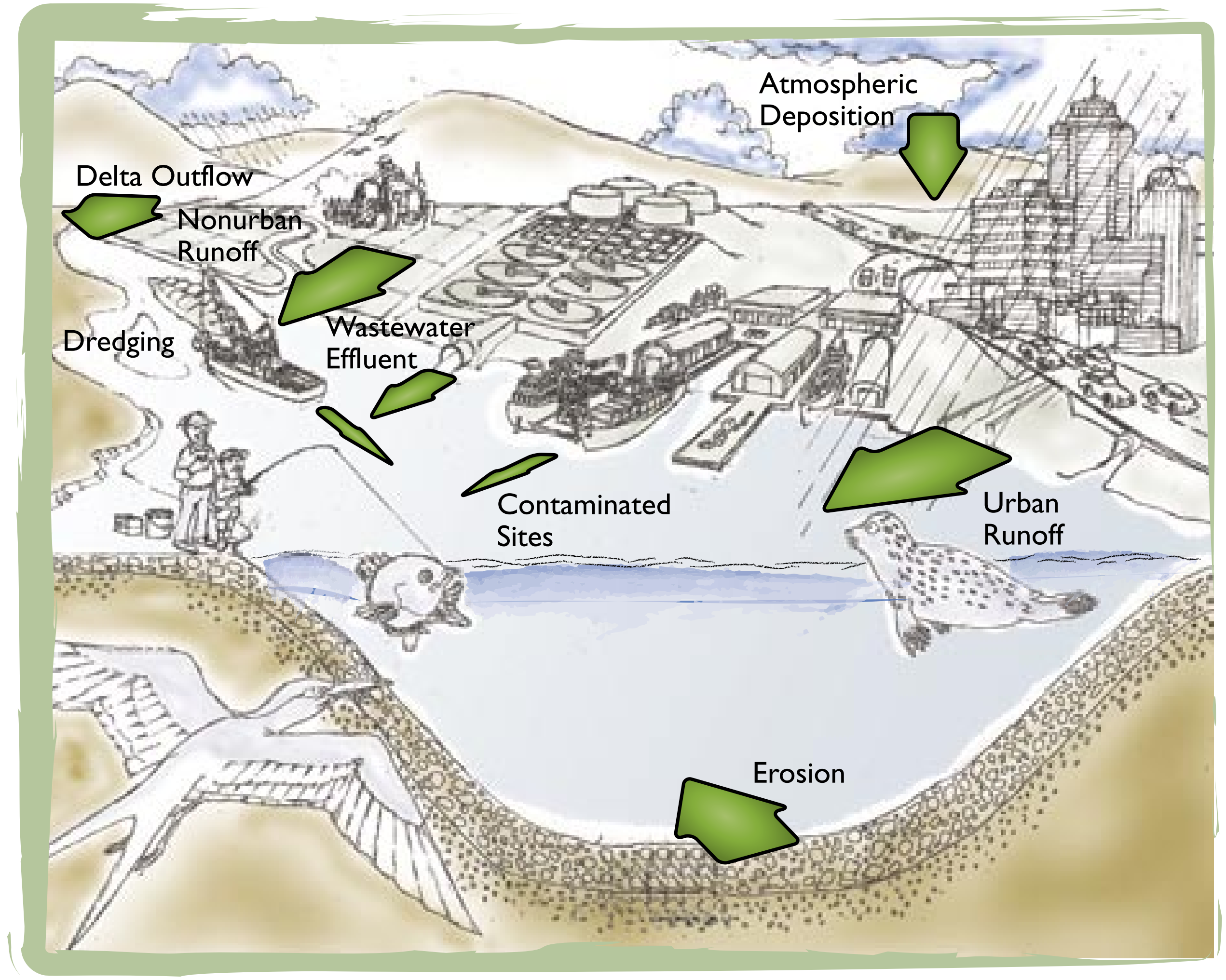


Figure 1. Legacy pesticides enter San Francisco Bay in runoff from the mostly-agricultural Central Valley, in runoff from the more urban, local watersheds, in wastewater from sewage treatment plants, in industrial effluent, as atmospheric deposition, and from resuspension of sediments that are eroded or dredged from deeper deposits. Size of arrow indicates the relative mass of the input, and the color indicates how concentrated the input is.

Because of the widespread use of the legacy pesticides and the enormity of the area that feeds the Bay (almost 60,000 square miles) runoff from the Central Valley and runoff from the local watersheds are the major sources of legacy pesticides to the Bay (**Table 2**). To estimate inputs from the Central Valley, we used data on contaminant concentrations collected as part of a Regional Monitoring Program (RMP) special study at Mallard Island, located just downstream from the confluence of the Sacramento and San Joaquin rivers (Leatherbarrow et al., 2004) in conjunction with continuous turbidity data that have been collected by the U.S. Geological Survey (USGS) (methods described

Runoff from the Central Valley and runoff from the local watersheds are the major inputs of legacy pesticides to the Bay

in McKee et al., 2002; McKee and Foe, 2002). Our estimates of total loads span an order of magnitude, largely because of variability in outflow and sediment load through the Sacramento-San Joaquin Delta.

Loads from the local watersheds were even more difficult to estimate, because there is so little information. We used the same methods used to estimate inputs from the Central Valley, substituting data from the Guadalupe River for the data from the Delta, and extrapolating to the total area of all the local watersheds. These estimates span more than an order of magnitude and are particularly uncertain, because it is not clear that the Guadalupe River is a good representative of all the local watersheds.

Our estimates indicate that for DDTs and dieldrin, the Central Valley and the local watersheds contribute roughly equivalent inputs to the Bay. For chlordanes, the local watersheds are bigger contributors. These differences may reflect the different histories of the areas. While the Central Valley has an intense history of agriculture, the local watersheds were urbanized during the post-World War II period. DDTs and dieldrin were typically associated with agricultural uses, while chlordanes were primarily used to control termites and ants in residential and commercial areas.

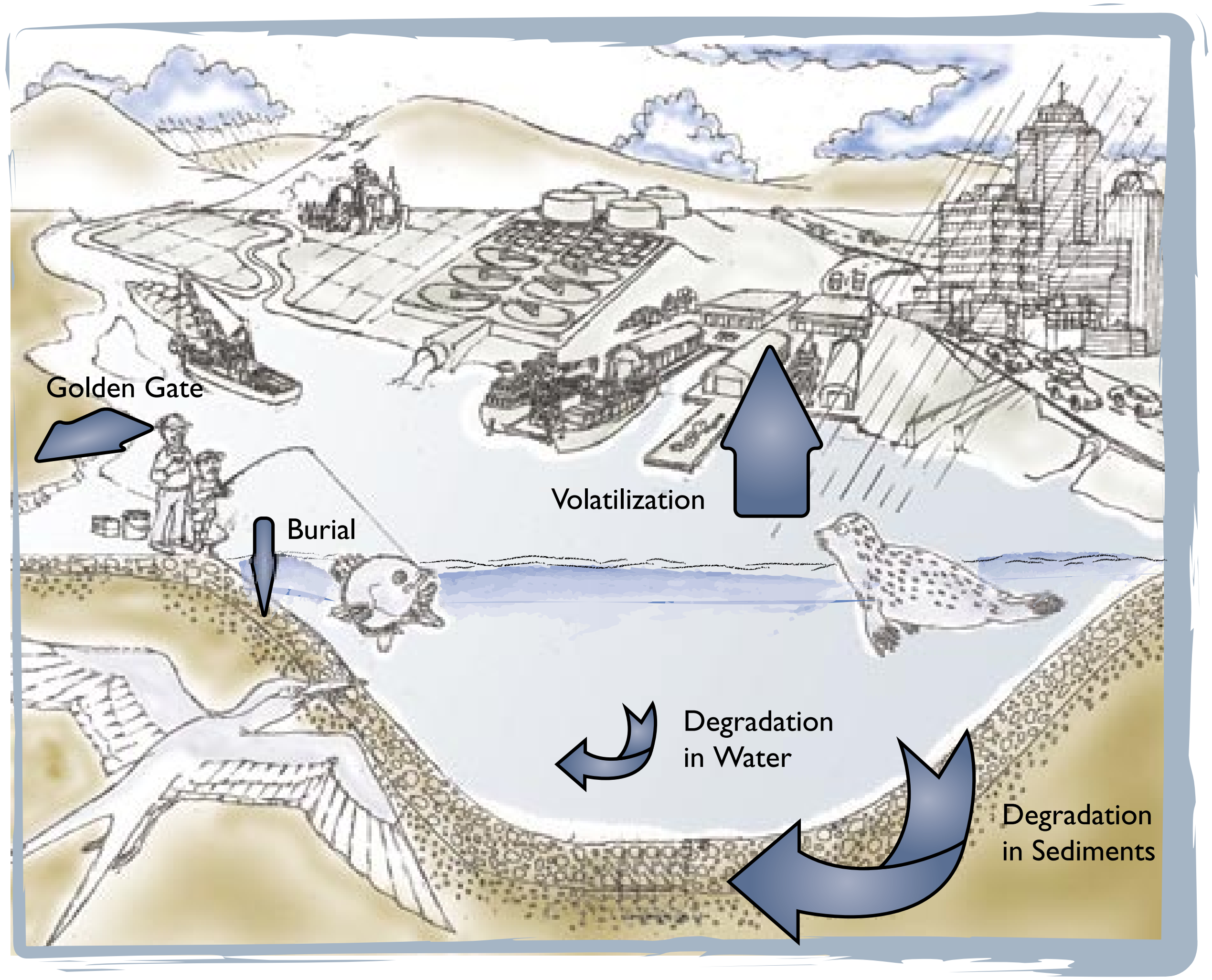


Figure 2. Legacy pesticides are lost from the Bay through degradation in the water, degradation in the sediments, burial in deeper sediments, transportation through the Golden Gate, or volatilization to the atmosphere.

Estimates of loads from municipal sewage are based on concentration ranges measured in effluents (Yee et al., 2001), and loads from industrial effluent are simply assumed to be less than those from municipal discharges. There are no local data on atmospheric deposition, so we extrapolated from data from the Great Lakes and Galveston Bay, Texas. We calculated estimated loads from erosion of deeply buried sediments and from dredging using methods and assumptions that had been developed for the mercury TMDL report for San Francisco Bay (Johnson and Looker, 2003).

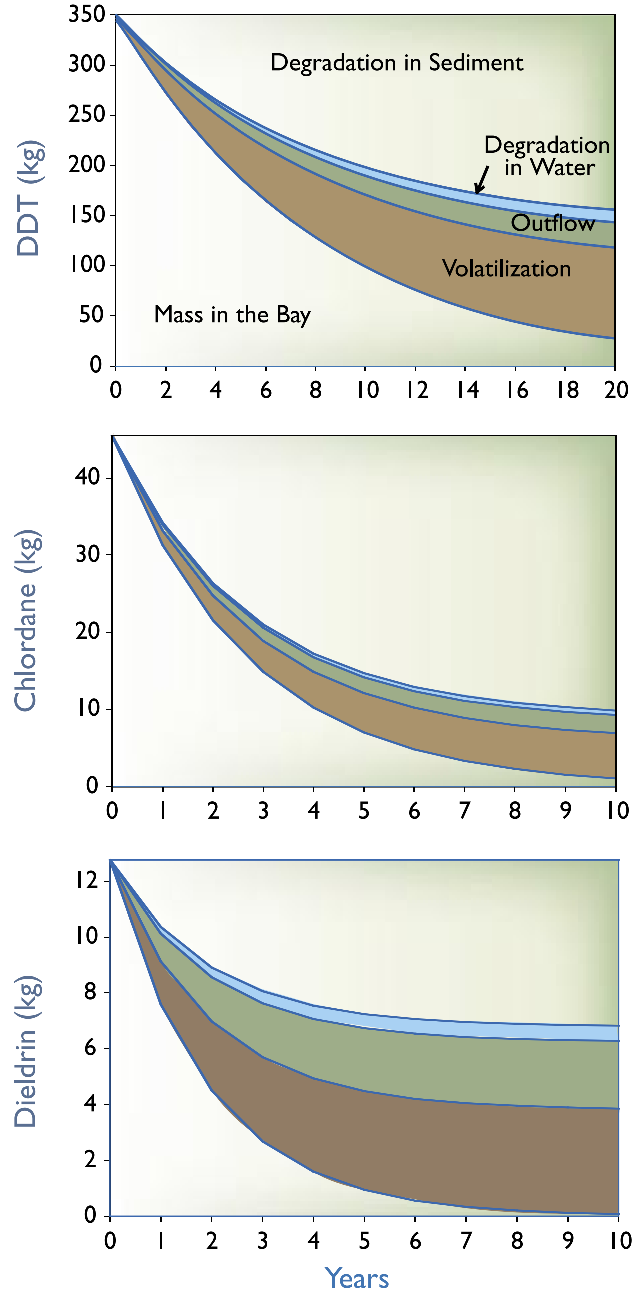


Table 2. Sources of legacy pesticides

Pathway	DDTs	Chlordanes	Dieldrin
Runoff from the Central Valley	15 (5 – 40)	2 (0.7 – 5)	5 (2 – 13)
Runoff from local watersheds	40 (9 – 190)	30 (7 – 160)	3 (0.7 – 15)
Municipal wastewater discharge	0.2 (0.02 – 2)	0.1 (0.003 – 2)	0.06 (0.008 – 0.4)
Industrial wastewater discharge	<0.2	<0.1	<0.06
Atmospheric deposition	1 (0.02 – 2)	0.9	1 (0.2 – 2)
Erosion of deep sediment deposits	9 (0.2 – 18)	2 (0 – 4)	0.2 (0 – 0.6)
Resuspension of dredged material	-2 (-3 – -0.03)	-0.3 (-0.6 – 0)	-0.03 (-0.1 – 0)
Total Best Estimate	60 (10 – 250)	30 (10 – 170)	10 (3 – 30)

Table 2. Runoff from the Central Valley and runoff from local watersheds are the largest sources of legacy pesticides to San Francisco Bay. This table shows our best estimate of loads, followed by the range (in parentheses) in kg/year. The greater relative input of chlordanes from local watersheds may reflect greater urbanization compared to the Central Valley. DDTs and dieldrin were largely used in agriculture, while chlordanes were primarily used in residential and commercial applications. The ranges reflect the uncertainty in our estimates.

Figure 3. Degradation in the sediments and volatilization to the atmosphere are major loss pathways for DDTs, chlordanes, and dieldrin. Transport through the Golden Gate is also a significant loss pathway for dieldrin, which is the most soluble of the legacy pesticides. These graphs show model predictions of degradation, transport, and volatilization of existing pesticides in the Bay over a 10-year period. The graphs illustrate expected trends with no additional inputs of legacy pesticides to the Bay.

What Happens to Legacy Pesticides in the Bay?

Once in the Bay, legacy pesticides may be degraded in the water, degraded in the active sediment layer, buried in deeper sediments, transported through the Golden Gate, or volatilized to the atmosphere (**Figure 2**).

Best estimates of half-lives of the legacy pesticides in sediments are 9 years for DDTs, 2.3 years for chlordanes, and 2.8 years for dieldrin, although there is a lot of variability in these estimates (Leatherbarrow et al., 2003). Degradation rates in the water are faster, but since most of the pesticides found in the Bay are in

Measurements of legacy pesticides in fish and in water samples confirm that the pesticides could pose a risk to fishermen and their families and friends who eat sport fish caught in the Bay

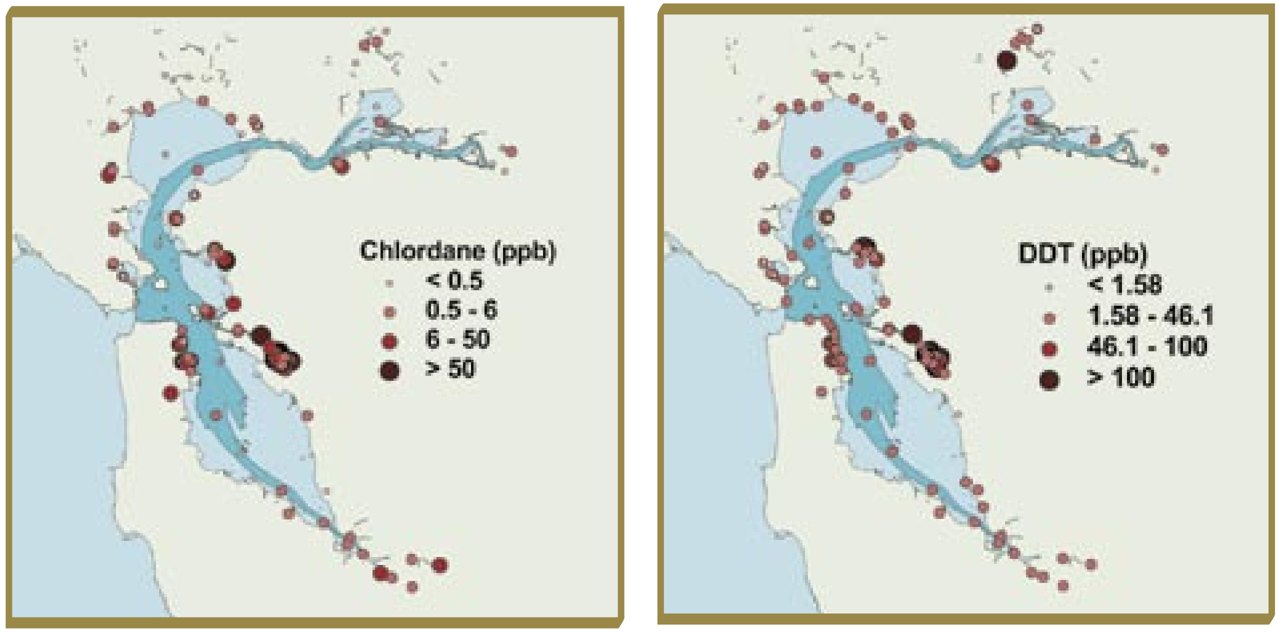


Figure 4. DDT and chlordane concentrations in Bay sediment are greatest in the shallower areas at the urbanized edges of the Bay, such as Oakland Harbor. The data included in the figures are average concentrations at locations monitored by the RMP during 1993-1999, the pilot RMP in 1991-1992, the Bay Protection and Toxic Cleanup Program in 1994-1999.

the sediments, degradation in water tends to be less important.

In areas where sediments are accumulating, burial is an important route of loss of pollutants from the active part of the Bay. However, we assumed that for the Bay as a whole, loss to burial was zero. Bathymetric studies (such as Foxgrover et al., 2003) have indicated that in recent decades, there has been net erosion rather than net deposition of sediments in the Bay.

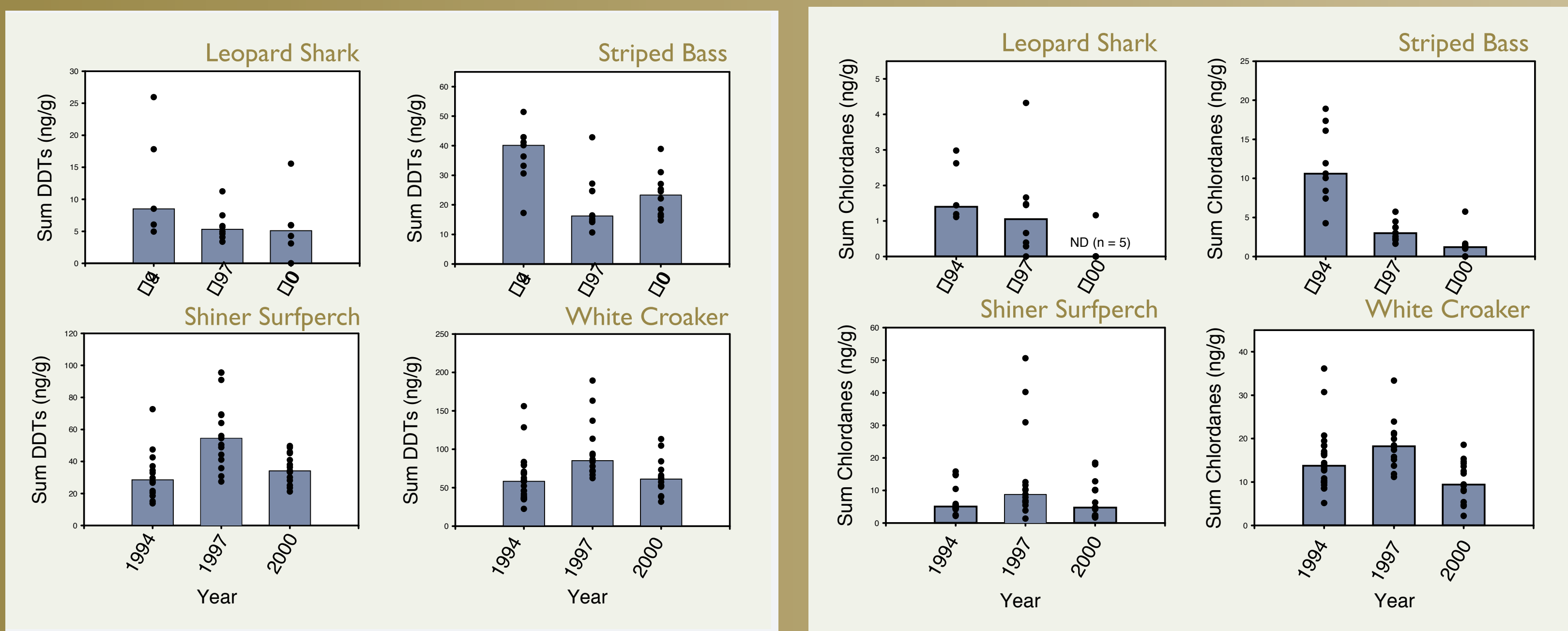
Transport of the pesticides through the Golden Gate depends on the residence time of water and sediment in the Bay and its subembayments and is controlled by surface runoff, tidal action, and wind-driven waves. There have been no field studies of air-water exchange of legacy pesticides in San Francisco Bay; our estimates of volatilization rates are derived from information in the literature.

Modeling (Leatherbarrow et al., 2003) suggests that degradation of the pesticides in the active layer of sediment is the major pathway of removing DDTs, chlordanes, and dieldrin from San Francisco Bay (**Figure 3**). For DDTs and dieldrin, volatilization to the atmosphere is also important. And for dieldrin, the most water-soluble of the pesticides, transport through the Golden Gate is also significant.

Health Risks to Humans and Wildlife

All the legacy pesticides biomagnify, that is, they increase in concentration at each step of the food chain. For San Francisco Bay, the top of the food chain includes anglers and the families and friends who share their catches, and wildlife, particularly fish-eating birds and seals.

We looked for possible effects on the ecology of the Bay and on human health. Since the OEHHA



Bars show medians, points are individual samples.

Figure 5. Temporal patterns of DDTs and chlordanes in leopard shark, striped bass, shiner surfperch, and white croaker show no pattern of decline in recent years. Concentrations of DDTs and chlordanes are highest in shiner surfperch and white croaker, the fattiest of the sport fish. Concentrations of dieldrin in fish tissues are usually below detection limits.

interim advisory against consuming more than two meals of sport fish from the Bay per month remains in place, we reviewed fish tissue data. We also reviewed the most up-to-date information on water, sediments, and wildlife. Our goals were to determine whether concentrations of the legacy pesticides were high enough to affect the ecological communities in the Bay and whether they continue to pose the public-health risks assumed by the OEHHA advisory.

RMP water data, collected since 1993, show that legacy pesticides in the water column are not acutely toxic to marine life. Throughout the Bay concentrations of legacy pesticides have been consistently well below the federal and state water quality standards designed to protect marine life.

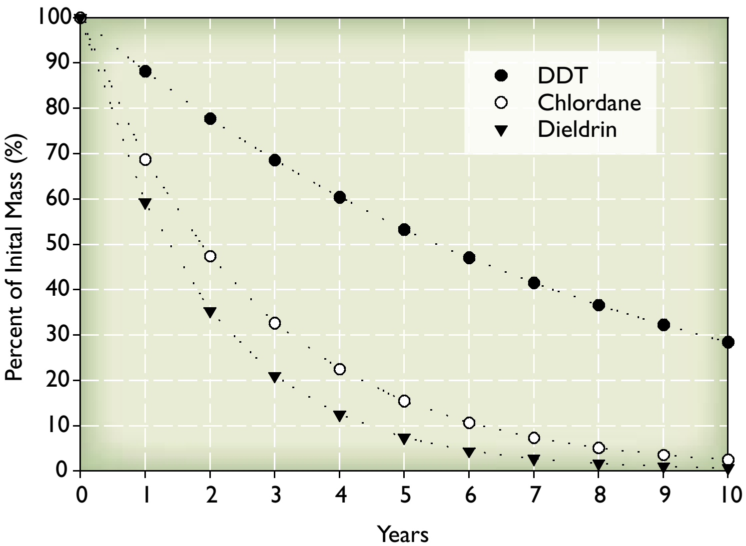


Figure 6. A fate model predicts that if there were no additional inputs of pesticides to the Bay, 95% of DDTs would be removed within 25 years. Removal of 95% of chlordanes would take 8 years, and removal of 95% of dieldrin would take 6 years. Realistic estimates of removal rates are much longer. In fact, the model predicts that using our current best estimates of inputs of DDTs and chlordanes to the Bay, we can expect no decline at all if inputs remain constant at present values.

Table 3. Legacy pesticide risks

	Aquatic Toxicity	Sediment Toxicity	Fish Consumption	Bird Eggs
DDTs	Low	Low	Medium	Low
Chlordanes	Low	Medium	Low	Low
Dieldrin	Low	Low	Medium	Low

Table 3. Chlordanes pose a medium risk for animals living in the sediments, and DDTs and dieldrin pose a medium risk for people who eat fish from the Bay. Risks to organisms living in the water column and to bird eggs are low.

Sediment data from the RMP and the Bay Protection and Toxic Cleanup Program indicate that chlordanes may be present in concentrations that are harmful to animals living in Bay sediments. There are no regulatory standards for pesticides in sediments, but about 10% of the chlordane samples were higher than the concentration found to be toxic in a literature review of toxic effects. Further, a special study conducted for the Bay Protection and Toxic Cleanup Program specifically implicated chlordanes as key contaminants correlated with sediment toxicity in the Bay (Thompson et al., 1999). For all the pesticides, concentrations in sediments tend to be higher in the shallower areas at the urbanized edges of the Bay, such as Oakland Harbor (**Figure 4**).

Measurements of legacy pesticides in fish and in water samples confirm that the pesticides, particularly DDTs and dieldrin, could pose a risk to fishermen and their families and friends who eat sport fish caught in the Bay, although the data are not sufficient to make any definite statement of the risks of eating seafood. Nor are the data sufficient to delineate specific geographic areas of concern.

The most recent fish data were available from 1994, 1997, and 2000 (Fairey et al., 1997, Davis et al., 1999, Greenfield et al., 2003). Concentrations of DDTs, chlordanes, and dieldrin are all highest in two of the fattiest fish species, shiner surfperch and white croaker (**Figure 5**). This result was expected, because the legacy pesticides accumulate in fatty tissues. Concentrations of pesticides in fish that are more popular among anglers, such as striped bass, are lower.

Despite the available data, it is difficult to determine the level of concern that we should have about human exposure to legacy pesticides through consumption of seafood from the Bay. For fish, there are no standards, above which the state or the federal government are concerned about consumption of sport fish. Non-regulatory "screening values" or thresholds of concern can be calculated, but those values may vary widely, depending on a number of factors. For example, screening values depend on the amount of risk that has been determined to be acceptable (typically one additional cancer

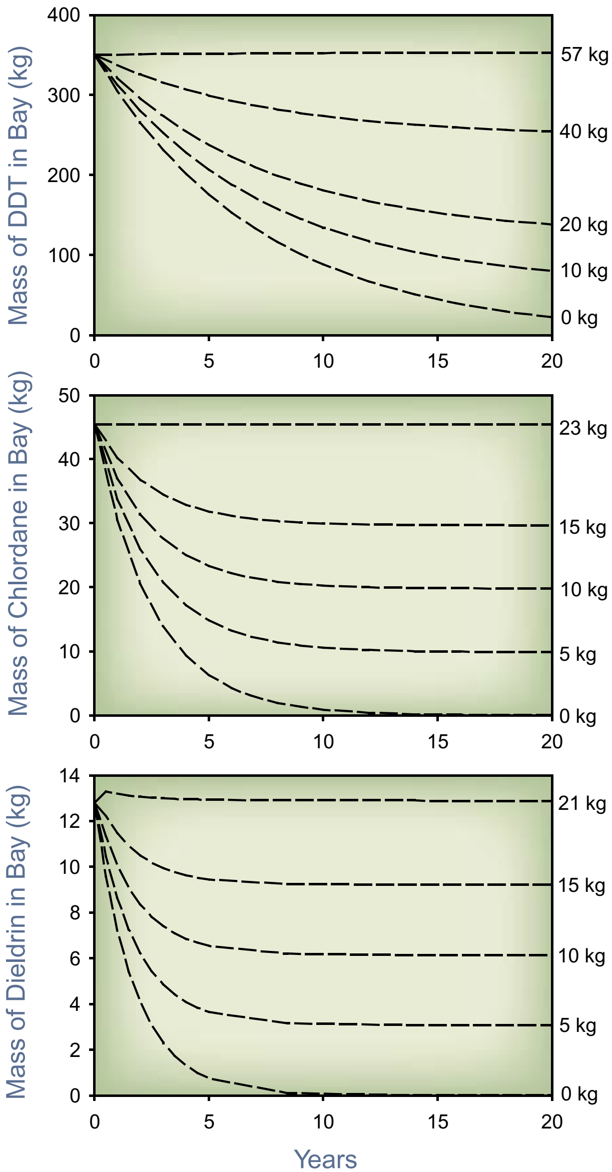


Figure 7. Model estimates show the change in legacy pesticide mass in San Francisco Bay, assuming varying levels of constant continued input. Under our current best estimates of pesticide inputs, 60 kg DDTs, 30 kg chlordanes, and 10 kg dieldrin per year), the fate model predicts no decline in DDTs or chlordanes in the Bay if these inputs remain constant over the next 20 years.

in 10,000 to 10,000,000 people), the degree to which researchers believe the pesticides are carcinogenic (which may change as further research is conducted), and the amount of fish that people are assumed to eat (anywhere from zero to 14 meals per month, depending on the study).

In the case of dieldrin, most of the RMP measurements were "below detection limits," that is, the analytical methods are not sensitive enough to measure dieldrin in the range in which we are interested. This analytical constraint makes the risk of consuming contaminated seafood impossible to determine.

The fish data are also not extensive enough for us to determine whether there are "hot spots," areas with especially contaminated fish, which could be a problem for people who depend on fishing for survival. However, water data from the RMP bolstered conclusions from the fish data and allowed for some assessment of geographic differences. Highest levels of legacy pesticides in water, sometimes exceeding the regulatory standards for protection of human health, were collected at the most southern stations, upstream from the Lower South Bay in San Jose and Sunnyvale. Concentrations in Central San Francisco Bay generally met standards.

Data on concentrations of legacy pesticides in the birds and mammals of San Francisco Bay are unfortunately scarce, but the available data do not suggest any cause for concern. In 1999-2001, the Coastal Intensive Sites Network (CISNet) found elevated concentrations of DDE, a breakdown product of DDT, and measurable concentrations of chlordanes and dieldrin in the eggs of the Double-crested Cormorant, a year-round, fish-eating Bay resident (data courtesy of J. Davis). However, the levels were not as high as those thought to cause reproductive problems in the species.

To sum up, on a range of low to high, the risks from legacy pesticides in the Bay are low to medium (**Table 3**). Chlordanes pose a medium risk for animals living in the sediments, and DDTs and dieldrin pose a medium risk for people who eat fish from the Bay. In contrast, mercury, PCBs, and dioxins pose a higher risk to seafood consumers, and mercury poses a higher risk to fish-eating birds.

The Forecast

Our modeling studies indicate that if there were no new inputs of legacy pesticides to the Bay, 95% of the DDTs would be removed within 25 years, 95% of the chlordanes would be removed within 8 years, and 95% of the dieldrin would be removed within 6 years (**Figure 6**).

Of course, there are continued inputs of legacy pesticides to San Francisco Bay, so realistic estimates of the time it will take to clean up the Bay are much longer. In fact, if inputs of DDTs and chlordanes remained at the levels of our current best estimates, we could expect little or no decline in pesticide levels in the Bay (**Figure 7**). Over the long term, there has been evidence of declines in concentrations of legacy pesticides in bivalves and in fish. The State Mussel Watch Program and the RMP have documented obvious declines in pesticides in bivalves since the 1980s, although the rate of decline has slowed in recent years (Gunther et al., 1999; Leatherbarrow et al., 2003). Likewise, median concentrations of DDTs in shiner surfperch from a 1965 study were 40 times higher than those measured by the RMP in 2000 (Greenfield et al., 2003). But more recently, fish data from 1994, 1997, and 2000 have generally shown no pattern of decline in pesticide concentrations. And while concentrations of pesticides measured in RMP water samples appeared to decline during 1993-2001, these years also represent a transition from predominantly wet years when more pesticides would be expected to enter the Bay from the watersheds (1995-1998) to predominantly dry ones (1999-2001).

For water quality managers and the scientific community, there is a challenge in deciding how to fill information gaps. The information gaps are many. For example, there is great uncertainty in the calculations of inputs from the Central Valley and the local watersheds. There are also great uncertainties in the model used to describe the fate of the pesticides in the Bay. There is insufficient information on the extent and delineation of hot spots within the Bay. And while we have determined that existing levels of legacy pesticides may pose a risk to ecological communities or human health, those determinations are based on numerous assumptions and limited by a lack of defined standards for levels of contaminants that could be called “acceptable.” Water qualiy managers also have the challenge of determining whether there are control measures, remediation, or regulatory actions that should be taken now, even with the existing uncertainties.

The Surface Water Ambient Monitoring Program (SWAMP) in the San Francisco Bay Area

Karen Taberski (KTaberski@waterboards.ca.gov) and Steve Moore, San Francisco Bay Regional Water Quality Control Board

Key Points

- The SWAMP, the RMP, and local watershed monitoring programs are the three components of a Water Board strategy to comprehensively monitor water quality in the Bay Area
- The SWAMP is monitoring watersheds, lakes/reservoirs, and bays and estuaries other than San Francisco Bay
- The two primary elements of the SWAMP in the Bay Area are monitoring pollutants in fish in reservoirs and coastal areas and watershed screening-level monitoring of ambient water quality
- Fish from many reservoirs in the region and Tomales Bay are not entirely safe to eat due to elevated concentrations of mercury, PCBs, and legacy pesticides and consumption advisories have been issued
- Water quality problems in streams appear to be more related to traditional parameters such as temperature, dissolved oxygen, and pathogens rather than to elevated levels of pollutants

A Regional Water Quality Monitoring Strategy for the Bay Area

In the Bay Area, the RMP has provided ambient monitoring information vital to regulatory decision making for estuarine waters of the San Francisco Bay Region. Freshwaters of the Region have not been monitored at a comparable level. In 1999 the need for a statewide ambient monitoring program that covers all waters was acknowledged with the enactment of California Assembly Bill 982 (Water Code Section 13192). This bill required that the State Water Resources Control Board (SWRCB) assess and report on State water quality monitoring programs and propose a comprehensive surface water quality monitoring program. In the SWRCB Report to the Legislature entitled “Proposal for a Comprehensive Ambient Surface Water Quality Monitoring Program,” the SWRCB proposed to restructure existing water quality monitoring programs into a new program, the Surface Water Ambient Monitoring Program (SWAMP). This proposal was designed to be a comprehensive statewide monitoring program focused on providing the information needed to effectively manage the State’s water resources. Unfortunately, the budget proposed in that plan was 20 times higher than what was appropriated. In spite of this, the SWAMP has moved forward with a reduced scope and narrower objectives. SWAMP data from the entire state will be available on a web site by the end of 2005.

Data from the SWAMP will be used to improve the State’s water quality assessment and impaired water bodies list, required under Sections 305 (b) and 303 (d) of the federal Clean Water Act. Currently the annual budget for the SWAMP in the San Francisco Bay Region is less than one tenth of the RMP budget, limiting the scope of water quality assessment that can be accomplished. The Program has focused on waters other than those monitored by the RMP.

In 1999 the San Francisco Bay Regional Water Quality Control Board (Water Board) developed a Regional Monitoring and Assessment Strategy (RMAS) in order to organize and expand monitoring associated with the Water Board on all water bodies in the San Francisco Bay Region. The RMAS recognized that receiving water monitoring required in municipal stormwater discharge permits and other programs should be used by the Water Board, where appropriate, for fulfilling Clean Water Act water quality assessment requirements. SWAMP is being used in this Region to implement the RMAS for areas not monitored by the RMP, and to provide a template for watershed ambient monitoring requirements in permits.

The three components of the RMAS are:

1) Water Board-led activities under the SWAMP, concentrating on monitoring watersheds, lakes/reservoirs, and bays and estuaries other than San Francisco Bay, incorporating previous programs such as State Mussel Watch (SMW), the Toxic Substances Monitoring Program (TSMP) and the Coastal Fish Contamination Program (CFCP);
2) Partner-led watershed monitoring programs that are being conducted by local agencies/groups with similar goals, structure, scope, protocols, and quality assurance as the Regional Board-led activities, including receiving water monitoring requirements of municipal stormwater programs and citizen monitoring; and
3) The San Francisco Estuary Regional Monitoring Program (RMP).

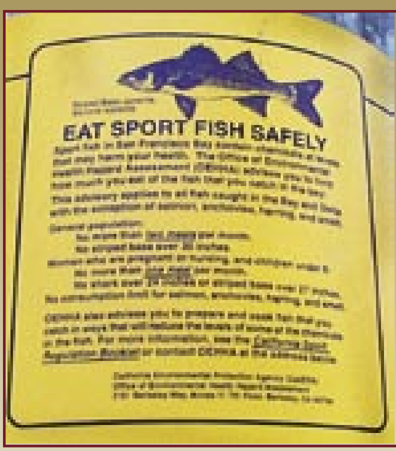
This is the fifth year of the Water Board's SWAMP activities. Two components of these Water Board-led activities are:

1) Studies on contaminants in fish - monitoring fish for contaminant levels in reservoirs and coastal areas where people catch and consume fish; and
2) Watershed screening-level monitoring - monitoring to characterize ambient water quality in all watersheds and establish regional reference sites.

SWAMP Goal and Objectives

The goal of the SWAMP in the San Francisco Bay Region is to monitor and assess water quality in all of the watersheds in the region to determine whether water quality standards are met and beneficial uses are protected. The highest priorities for regional SWAMP activities are to answer the questions:

Protecting Fish Consumers



FISH CONSUMPTION ADVISORY

The following text is taken from the interim fish consumption advisory for San Francisco Bay. The full text is available at http://www.oehha.org/fish/nor_cal/int-ha.html.

- Adults should limit their consumption of San Francisco Bay sport fish to, at most, two meals per month.
- Adults should not eat any striped bass over 35 inches.
- Women who are pregnant or who may become pregnant, or who are breast-feeding, and children under 6, should not eat more than one meal per month and, in addition, should not eat any meals of large shark (over 24 inches) or large striped bass (over 27 inches).

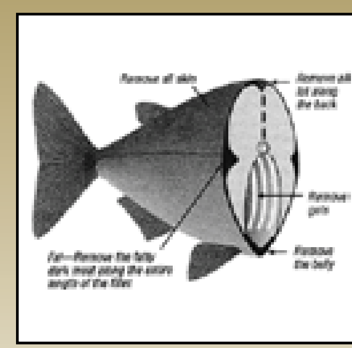


Figure 1. The two primary elements of the SWAMP in the Bay Area are monitoring pollutants in fish in reservoirs and coastal areas and watershed screening-level monitoring of ambient water quality. Sport fish samples from 10 reservoirs and Tomales Bay were analyzed from 2000 to 2002.

1) Is it safe to eat the fish?
2) Is it safe to swim in the water?
3) Is the water a suitable source of drinking water? and
4) Is aquatic life protected?

The objectives of the Program in the San Francisco Bay Region are to:

1. Measure contaminant levels in fish in areas where people catch and consume fish to determine if health advisories are needed.
2. Measure environmental stressors (pollutants or other water quality parameters), biological effects (e.g., toxicity tests), and ecological indicators (e.g., benthic community analysis) to evaluate whether beneficial uses are being protected.
3. Use a design that allows for evaluation of spatial and temporal trends in the watersheds of the region.
4. Identify minimally disturbed reference conditions.
5. Determine if impacts are associated with specific land uses and/or water management.
6. Use standard sampling protocols, SWAMP QAMP procedures, and the SWAMP database to provide statewide consistency and availability of data.
7. Evaluate monitoring tools in watersheds in order to identify the best environmental indicators to achieve the goal of the Program.
8. Generate data and associated information for the development of indices to evaluate ecological indicators (e.g., IBIs for macroinvertebrates).

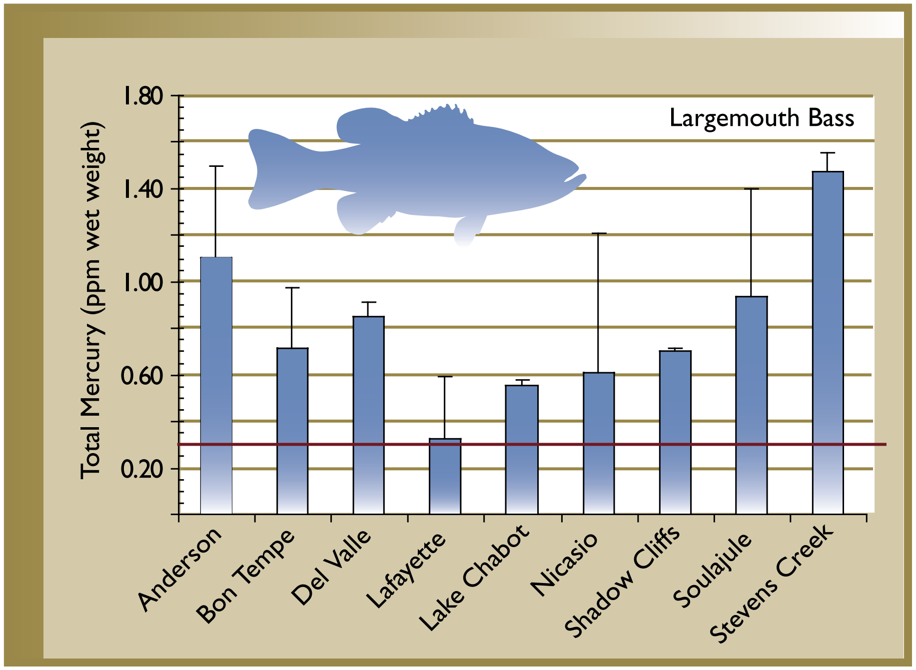


Figure 2. Fish from many reservoirs in the region and Tomales Bay are not entirely safe to eat due to elevated concentrations of mercury, PCBs, and legacy pesticides and consumption advisories have been issued. Largemouth bass was the species that accumulated the highest mercury concentrations in regional reservoirs. Average mercury concentrations (± standard deviation), line indicates threshold for human health concern (0.3 ppm).

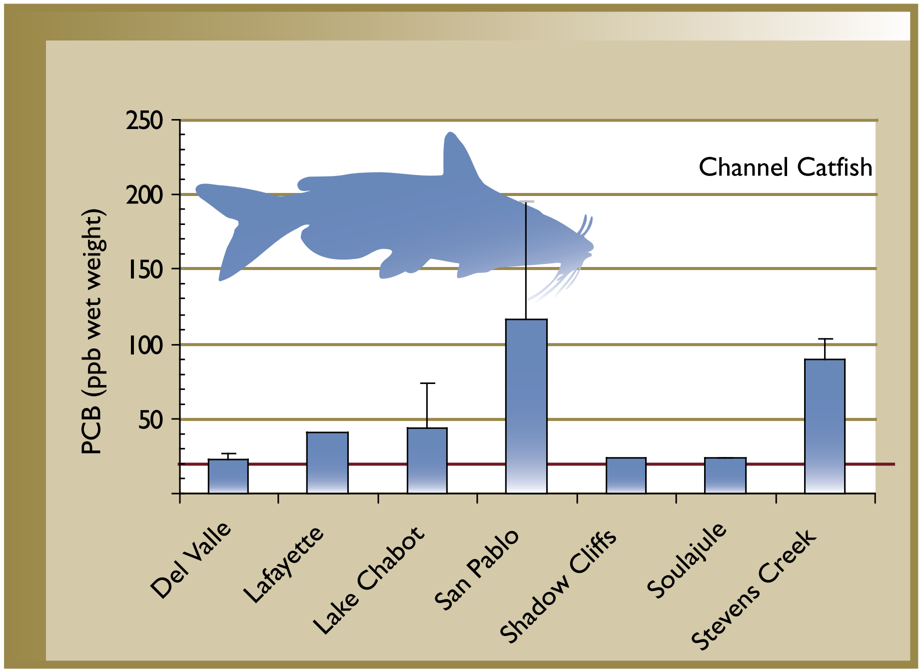


Figure 3. Channel catfish was the species that accumulated the highest PCB concentrations in regional reservoirs. Average PCB concentrations (± standard deviation), line indicates threshold for human health concern (20 ppb).

Contaminants in Fish: Some Concerns for Human Health

Introduction

In November 1997 the Office of Environmental Health Hazard Assessment (OEHHA) sampled fish from San Pablo Reservoir and found high concentrations of mercury, PCBs, and pesticides (Brodberg and Pollock 1999). In 1998 the Water Board and U.S. EPA conducted an emergency cleanup of an abandoned mercury mine in the Walker Creek watershed. Studies associated with this cleanup raised concerns over mercury concentrations in Tomales Bay fish and shellfish. These and other water quality concerns prompted the Water Board to direct funds to better characterize the potential risk to human health from consuming species caught while fishing in the Region's reservoirs and coastal waters.

Study Design

Fish from Tomales Bay and ten commonly-fished reservoirs were collected and their edible tissues analyzed for contaminants. Available information on fishing activity suggested that fish should be sampled from Bon Tempe, Nicasio and Soulajule Reservoirs in Marin County; San Pablo and Lafayette Reservoirs in Contra Costa County; Lake Chabot, Shadow Cliffs and Del Valle Reservoirs in Alameda County; and Stevens Creek and Anderson Reservoirs in Santa Clara County (**Figure 1**). Fish and crabs were also sampled from the San Mateo Coast and one composite sample of salmon was collected near the Farallone Islands. All edible fish tissue studies were conducted in cooperation with OEHHA.

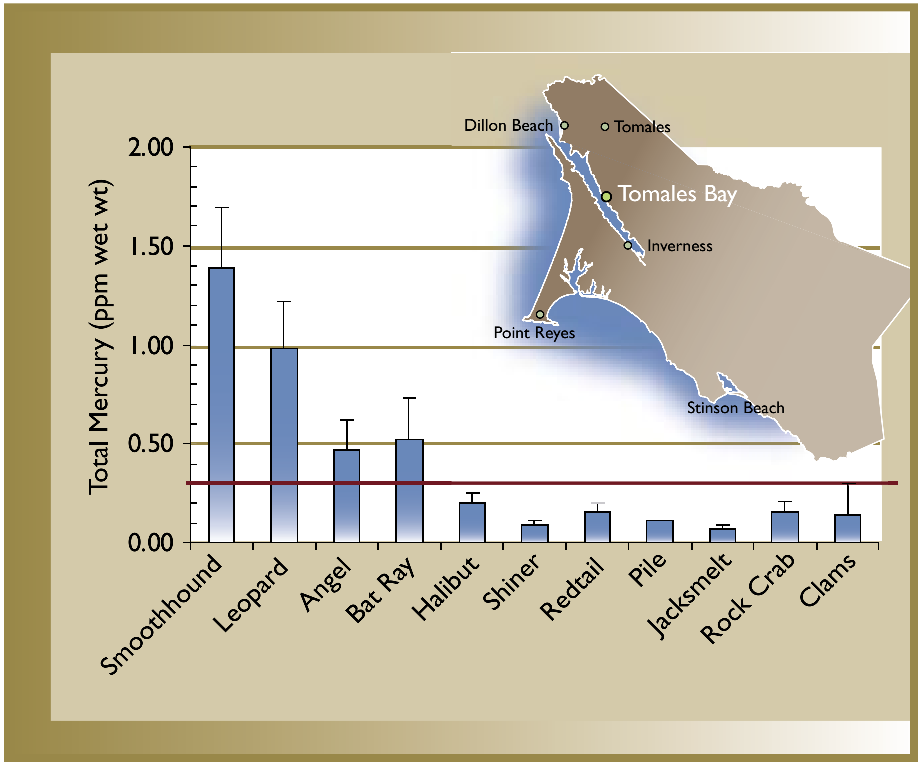


Figure 4. Two shark species, smoothhound and leopard shark, accumulated the highest mercury concentrations in Tomales Bay. Sufficient mercury data were available from Tomales Bay for OEHHA to set consumption guidelines for California halibut, redtail surfperch, shiner surfperch, jacksmelt, leopard shark, brown smoothhound shark, Pacific angel shark, bat ray, and red rock crab. Pile surfperch were also included in the advisory, based on data for other surfperch species. Since mercury concentrations were measured in commercially grown Tomales Bay shellfish, and elevated levels were not found, the OEHHA mercury advisory for Tomales Bay does NOT apply to commercial oysters, clams, or mussels. Average mercury concentrations (± standard deviation), line indicates threshold for human health concern (0.3 ppm).

Fish species targeted for collection in reservoirs in 2000-2002 were those frequently caught and consumed by recreational anglers: channel catfish, carp, rainbow trout, largemouth bass, bluegill, crappie and other sunfish. Of these, all but rainbow trout were collected, although a current effort is underway to fill this and other data gaps. Two or more species were collected in most reservoirs. Chemical concentrations in fish were compared to thresholds for human health concern ("screening values") developed by OEHHA (Brodberg and Pollock, 1999).

In Tomales Bay, information from past sampling efforts helped determine the fish species to target for collection. Where target species or numbers were not attainable, other species were collected. Species (and number of samples each) collected during one or both of the two sampling periods were California halibut (12), redtail surfperch (3), shiner surfperch (7), jacksmelt (7), leopard shark (18), brown smoothhound shark (12), Pacific angel shark (18), bat ray (12), pile surfperch (1), red rock crab (6), and resident clams (10).

Results

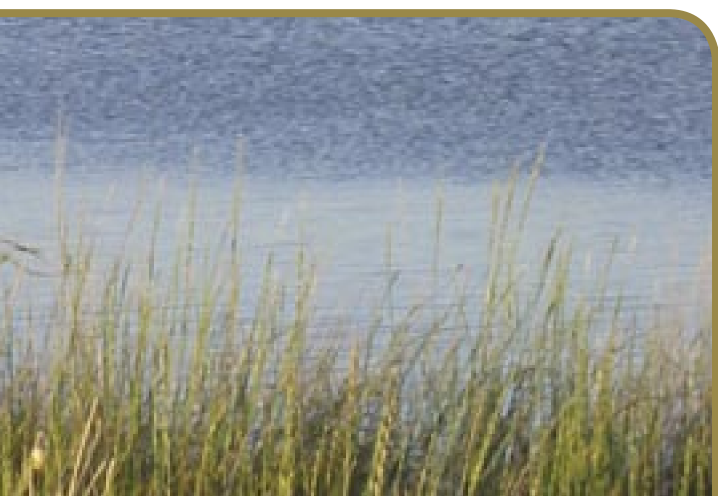
A report was completed in October 2004, entitled "Chemical Concentrations in Fish Tissues from Selected Reservoirs and Coastal Areas: San Francisco Bay Region." It is available on the Water Board's web site at http://www.waterboards.ca.gov/sanfranciscobay/.

These studies indicated that fish from many reservoirs in the region are not entirely safe to eat. Specific findings included the following:

- All ten reservoirs sampled yielded fish with edible tissue concentrations of mercury that exceed the OEHHA mercury Screening Value (SV) and U.S. Environmental Protection Agency (EPA) water quality criterion of 0.3 ppm (wet weight).
- Largemouth bass accumulated higher levels of mercury than the other fish species sampled, with concentrations averaging about 3 to 5 times higher than those for carp, channel catfish, and black crappie. Largemouth bass exceeded the OEHHA SV in all nine reservoirs from which they were collected (**Figure 2**). Largemouth bass from Soulajule, Stevens Creek, and Anderson Reservoirs had the highest concentrations of mercury.
- With the exception of Nicasio Reservoir, all of the reservoirs surveyed for organic chemicals (pesticides and PCBs) had PCB concentrations

above the OEHHA SV of 20 ppb wet weight (**Figure 3**).

- PCB concentrations were highest in carp, followed by channel catfish and largemouth bass. Carp in Lake Chabot had the highest mean concentrations of PCBs.
- Dieldrin exceeded the SV of 2 ppb (wet weight) in edible fish tissues from Lake Chabot, San Pablo and Stevens Creek Reservoirs, with the highest mean concentrations in carp and channel catfish from San Pablo Reservoir.
- Total chlordanes and total DDTs were both found above SVs in carp and channel catfish from Lake Chabot, San Pablo, and Stevens Creek Reservoirs.
- The highest tissue concentrations of total chlordanes were found in San Pablo Reservoir, while the highest total DDTs were found in Lake Chabot.
- Sufficient mercury data were available from Tomales Bay (**Figure 4**) for OEHHA to set consumption guidelines for California halibut, redtail surfperch, shiner surfperch, jacksmelt, leopard shark, brown smoothhound shark, Pacific angel shark, bat ray, and red rock crab. Pile surfperch were also included in the advisory, based on data for other surfperch species.
- Since mercury concentrations were measured in commercially grown Tomales Bay shellfish, and elevated levels were not found, the OEHHA mercury advisory for Tomales Bay does NOT apply to commercial oysters, clams, or mussels.
- Along the San Mateo Coast five of 21 samples of fish and shellfish had mercury concentrations above the OEHHA SV and one sample exceeded the SV for PCBs.
- The salmon composite from the Farallone Islands did not exceed any screening values.



After the study OEHHA and county health officials worked together to develop Interim Advisories for consuming fish in the sampled reservoirs based on the data in this report and earlier data collected by OEHHA. OEHHA developed a final advisory for Tomales Bay. Signs were developed in multiple languages to post at reservoirs through a collaborative effort between the East Bay Municipal Utility District, East Bay Regional Park District, Santa Clara Valley Water District, Marin Municipal Water District and the County Health Departments. The Department of Health Services will use this information in their ongoing outreach and education efforts on fish consumption. More information on consumption advisories can be found at: www.oehha.ca.gov/fish.html.

Different Problems in the Watersheds

Introduction

This is the fifth year of the regional watershed screening-level monitoring component of SWAMP. This monitoring is designed to answer the questions: "Is it safe to swim in the water?" and "Is aquatic life protected?" Watersheds that have been monitored are illustrated in Figure 5. The total area included in watershed monitoring each year has declined due to decreases in funding. An interpretive report is currently being assembled which will provide an analysis of the watershed monitoring data in years 1 and 2 of the program.

Study Design

The program employs a targeted sampling design, which rotates through watersheds to define baseline conditions based on available funding. Tier 1 monitoring is conducted at most or all stations in streams. Tier 1 is designed to obtain more spatial coverage in determining the basic water quality of the watershed, to identify reference sites, and to complement the evaluation of Tier 2 sites where potential impacts are being evaluated. Tier 1 monitoring includes benthic macroinvertebrate (sediment-dwelling organisms) collections ("bioassessments") along with visual physical habitat assessments and measurement of basic water quality parameters. Bioassessment sampling occurs in the spring. Continuous monitoring devices measuring temperature, pH, conductivity, dissolved oxygen, and water depth are deployed throughout the watersheds for a one-week period three times per year.

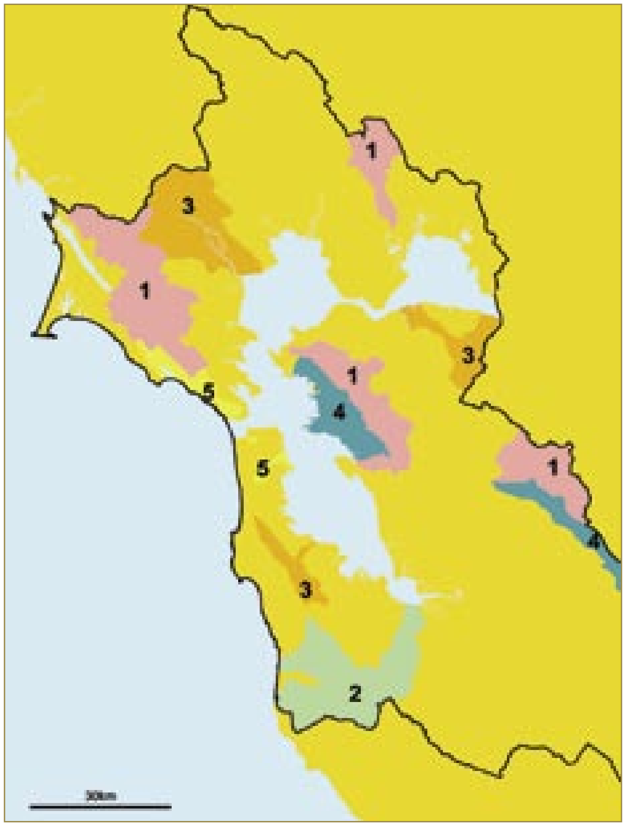


Figure 5. Screening-level monitoring of ambient water quality in watersheds is the second major element of the Bay Area SWAMP. Watersheds that have been monitored by the SWAMP from 2000 to the present. Numbers indicate year in which each watershed was sampled (1 = 2000, 2 = 2001, etc.). Water quality problems in the watersheds appear to be more related to traditional parameters such as temperature, dissolved oxygen, and pathogens rather than to elevated levels of pollutants. The table on the right lists the watersheds sampled by year.

Bay Area SWAMP Watersheds

Year 1	Year 2	Year 3	Year 4	Year 5 (in process)
Lagunitas	San Gregorio	Kirker	Baxter	Pine Gulch
Walker	Pescadero	Mt. Diablo	Cerrito	Audubon Canyon
Suisun	Butano	San Mateo	Codornices	Morses Gulch
Arroyo Las Positas	Stevens	Petaluma	Strawberry	Easkoot
San Pablo	Permanente		Temescal	Webb
Wildcat			Glen Echo	Redwood
San Leandro			Peralta	Tennessee Valley
			Sausal	Rodeo
			Lion	Rodeo Lagoon
			Arroyo Viejo	Lobos
			Arroyo Mocho	Islais
			Berkeley Aquatic Park	
			Lake Temescal	
			Lake Merritt	

Tier 2 of the design was developed to answer basic questions concerning protection of beneficial uses and potential impacts of land use and water management. Tier 2 stations are a subset of the Tier 1 stations. Tier 2 samples are collected during the wet season (e.g., January - March), spring (e.g., April - May), and the dry season (e.g., June - July). Additional samples and parameters to be evaluated in Tier 2 depend on the beneficial uses or land uses at or above a station or on previous data indicating a potential impact.

Toxicity and chemistry samples, including trace metals and organics, are collected at the same time the conventional water quality samples are collected. Tier 2 conventional water quality parameters include chlorophyll, ammonia, nitrate/nitrite, total nitrogen, phosphate, alkalinity, hardness, total and dissolved organic carbon (TOC and DOC), suspended solids concentration, total dissolved solids, and major cations and anions. At the bottom of each watershed in the non-tidal area one station is established, the integrator station, which integrates the contaminant conditions in the watershed and is used to attempt to identify which contaminants from that waterbody flow into the Bay or ocean. At these stations, sediment samples are collected for grain size analysis, TOC, sediment chemistry, and toxicity testing. Sediment sampling is concurrent with water sampling and occurs in the spring season. In evaluating potential impacts on aquatic life a weight of evidence approach will be used with water column chemistry, toxicity tests, and Tier 1 bioassessments.

The presence of pathogens can make a water body unsafe for swimming. In order to screen for pathogens, fecal coliforms and E.coli are measured at stations where there is water contact recreation and/or there are potential sewage inputs. Sites that exceed guidelines are sampled again a subsequent year. Trash assessments are conducted by Water Board personnel three times a year. Assessments are conducted to determine how much trash and what kind of trash is in a watershed, whether trash accumulates due to runoff or dumping, and how much trash accumulates over wet and dry periods.

Average water temperatures were above effects thresholds for salmonids at 30 out of 63 sites

In evaluating previous SWAMP data, temperature and dissolved oxygen are two parameters that frequently exceeded guidelines or objectives and can make a water body unsafe for aquatic life. To evaluate temporal variability, temperature sensors are being placed in watersheds that exhibited high temperatures in previous monitoring events and in areas that are sensitive salmonid habitats. The sensors will be deployed for nine months and therefore allow for a more comprehensive evaluation of temperature over a longer period of time.

Preliminary Regional Results for Years 1 and 2 of Watershed Monitoring

- In general, water quality problems in streams appear to be more related to traditional parameters such as temperature, dissolved oxygen, and pathogens rather than to elevated levels of contaminants, as has been observed in the Bay.

Bioassessments

- Benthic maroinvertebrate (BMI) assemblages generally reflect upstream land use. BMI assemblages in streams draining protected open space exhibited large numbers of species, especially taxa from the Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) insect orders, collectively known as "EPT" and indicative of good water quality. BMI assemblages at sites draining urban areas had low taxonomic richness and were numerically dominated by common pollution-tolerant taxa, such as Chironomidae (midges), Oligochaeta (segmented worms), and *Simulium sp.* (a blackfly). Benthic assemblages draining agricultural land use reflected a range of conditions from low to high taxa richness.
- In the region as a whole, sites grouped into three primary categories of BMI assemblages. When analyzed relative to land use, the number of relatively sensitive EPT taxa was greatest at sites draining open space and rural residential areas, intermediate at sites draining agriculture, grazing, and mixed use areas, and lowest in urban areas. These differences appeared to be at least partially associated with channel alteration and the condition of riparian habitat.
- In many watersheds, notably in San Leandro Creek and Stevens Creek, BMI assemblages decreased in quality and richness from upstream to downstream, reflecting effects of increasing urban land use and dams. In other watersheds, such as Lagunitas Creek and San Gregorio Creek, streams showed downstream recovery from poor upstream conditions. On Chileno Creek, in the Walker Creek watershed, a habitat restoration project resulted in improved biological conditions from degraded conditions upstream.
- Continuously flowing and intermittent streams tended to have distinct BMI assemblages. Many taxa with lengthy aquatic life stages, such as many Coleoptera (beetles) and long-lived stoneflies, were absent from streams that went dry during the summer.

Chemical Concentrations and Toxicity

- In general, measured concentrations of chemical pollutants were low in water samples. Grab samples from 27 selected sites, totaling 53 samples, were measured for trace metals, and of these, Basin Plan objectives or acute water quality

criteria for aquatic life protection were exceeded only for aluminum (13 samples), chromium (2 samples), copper (1 sample), and selenium (4 samples). Likewise, organic chemicals were seldom found above guidelines for aquatic life protection, the exceptions being the organophosphate pesticides diazinon (4 samples) and chlorpyrifos (3 samples).

- Three toxicity test species were exposed to grab samples from 26 sites in the region, totaling 59 samples, and of these, significant reductions in survival, growth, or reproduction were observed in 18 samples from 10 sites. Algal growth was reduced in 15 samples, invertebrate growth or survival was adversely affected in 3 samples, and fish larval growth or survival declined in 2 samples.

Temperature and Dissolved Oxygen

- Calculated maximum weekly average water temperatures were above effects thresholds for salmonids at 30 out of 63 sites during at least one of three seasons. A similar proportion of sites had dissolved oxygen concentrations below Basin Plan objectives

Sediment Quality

- Sediment chemistry (trace metals and organics) and toxicity were measured at sites near the base of each watershed. Since sediments tend to accumulate contaminants over time, and the sediment deposited at these sites was delivered from throughout the watershed, these samples were considered to integrate contaminants over extended temporal and spatial scales. One sediment sample was collected from each of 13 sites. Chemicals found at concentrations exceeding probable effects concentration (PEC) guideline values included chromium (5 sites), lead (1 site), and nickel (6 sites). Nickel and chromium are naturally abundant in Bay Area soils, and not considered a problem. Chemicals found at concentrations exceeding the lower threshold effects concentration (TEC) guideline values included arsenic (3 sites), cadmium (1 site), copper (4 sites), mercury (5 sites), zinc (2 sites), total DDTs (2 sites), dieldrin (1 site), and total PAHs (1 site).
- Sediments from 7 of the 13 sites were toxic to the amphipod Hyalella azteca. While toxicity was observed in sites with chemical concentrations above guideline values, there was no significant or apparent linear relationship between the overall level of contamination and the degree of toxicity.

Pathogen Indicators

- Pathogen indicators were analyzed at watershed sites where water contact recreation was most likely to occur, such as traditional swimming holes, beaches, or streams in public parks. Three types of bacterial counts were conducted for each sample: total coliform, fecal coliform, and E. coli. Most watersheds produced at least some samples that exceeded Basin Plan objectives for water contact recreation. Using the E. coli data, for example, samples exceeding the water contact recreation standards were collected from 3 of 4 sites in Lagunitas Creek, 0 of 1 site in Walker Creek, 3 of 5 sites in San Leandro Creek, 2 of 2 sites in Wildcat Creek, 2 of 2 sites in San Pablo Creek, 1 of 2 sites in Butano Creek, 1 of 6 sites in Pescadero Creek, 2 of 2 sites in San Gregorio Creek, 3 of 4 sites in Stevens Creek, and 1 of 1 site in Permanente Creek. These results are useful for targeting areas for more in-depth studies, but are not in themselves sufficient to characterize human health risk or to identify possible pathogen sources.

Analysis of the results, including the relationships between potential impacts and land use is continuing. More information on this program is available at http://www.waterboards.ca.gov/sanfranciscobay/download.htm.

Committee Members and RMP Participants

Committee Members

RMP Technical Review Committee

POTWs, Diane Griffin, EBMUD

South Bay Dischargers, Tom Hall, EOA Inc.

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

Industry, Dave Allen, USS-POSCO

Stormwater Agencies, Chris Sommers, EOA, Inc.

Dredgers, Andy Jahn, Port of Oakland

Regional Board, Karen Taberski, San Francisco Bay RWQCB

U.S. EPA, Kathleen Dadey, U.S. EPA

City of San Jose, **David Tucker**, City of San Jose

City/County of San Francisco, Michael Kellogg,

Army Corps, David Dwinelle, U.S. Army Corps of Engineers

RMP Technical Review Committee Chair in bold print

RMP Steering Committee

Small POTWs, Ken Kaufman, South Bayside System Authority

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

Large POTWs, Chuck Weir, East Bay Dischargers Authority

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

Industry, Dave Allen, USS-POSCO

Cooling Water, Steve Bauman, Mirant of California

Stormwater Agencies, Adam Olivieri, EOA, Inc.

Dredgers, Ellen Johnck, Bay Planning Coalition

SFBRWQCB, Dyan Whyte, San Francisco Bay RWQCB

Army Corps, David Dwinelle, U.S. Army Corps of Engineers

RMP Steering Committee Chair in bold print

RMP Participants

Municipal Dischargers

Burlingame Waste Water Treatment Plant

Central Contra Costa Sanitary District

Central Marin Sanitation Agency

City of Benicia

City of Calistoga

City of Palo Alto

City of Petaluma

City of Pinole/Hercules

City of Saint Helena

City and County of San Francisco

City of San Jose/Santa Clara

City of San Mateo

City of South San Francisco/San Bruno

City of Sunnyvale

Delta Diablo Sanitation District

East Bay Dischargers Authority

East Bay Municipal Utility District

Fairfield-Suisun Sewer District

Las Gallinas Valley Sanitation District

Marin County Sanitary District #5, Tiburon

Millbrae Waste Water Treatment Plant

Mountain View Sanitary District

Napa Sanitation District

Novato Sanitation District

Rodeo Sanitary District

San Francisco International Airport

Sausalito/Marin City Sanitation District

Sewerage Agency of Southern Marin

Sonoma County Water Agency

South Bayside System Authority

Town of Yountville

Union Sanitary District

Vallejo Sanitation and Flood Control District

West County Agency

Industrial Dischargers

C & H Sugar Company

Chevron Products Company

Dow Chemical Company

General Chemical Corporation

TOSCO – Rodeo Refinery

Rhodia, Inc.

Shell – Martinez Refining Company

Ultramar Inc - Avon Refinery

USS – POSCO Industries

Valero Refining Company

Cooling Water

Mirant of California

Stormwater

Alameda Countywide Clean Water Program

Caltrans

City and County of San Francisco

Contra Costa Clean Water Program

Fairfield-Suisun Urban Runoff Management Program

Marin County Stormwater Pollution Prevention Program

San Mateo Countywide Stormwater Pollution Prevention Program

Santa Clara Valley Urban Runoff Pollution

Vallejo Sanitation and Flood Control District

Dredgers

Chevron

City of Benicia

City of Vallejo Marina

Conoco Phillips

Corona Del Mar Homeowners Association

Loch Lomond Marina

Port of Oakland

Port of San Francisco

Ryer Island Boat Harbor

Shoonmaker Point Marina

U.S. Army Corps of Engineers

U.S. Army Reserve Center, Mare Island

Valero Refining Co.

Bay Sediment Budget: Sediment Accounting 101

David H. Schoellhamer (dschoell@usgs.gov), Megan A. Lionberger, Bruce E. Jaffe, Neil K. Ganju, Scott A. Wright, and Gregory G. Shellenbarger

U.S. Geological Survey

Key Points

- Comparison of a budget developed for 1955-1990 with a budget developed for 1995-2002 showed decreasing sediment inflow and increased amounts leaving the Bay to upland disposal and sand mining, resulting in an increased rate of erosion of sediment from the Bay floor
- Finding a way to shift disposal from the Ocean back to the Bay could provide sediment for restoration projects and decrease dredging costs
- Increased erosion of the Bay is mobilizing legacy contaminants from the sediment bed
- Restoration projects could increase erosion and mobilization of legacy contaminants
- Sand mining, ignored in previous budgets, removes almost twice as much sediment from the Bay as dredging

Dredging operations, the fate of contaminants associated with sediment, and restoration projects all depend on the amount of sediment that flows into and remains in the Bay. Dredgers are concerned with deposition in ports and shipping channels. To achieve water quality objectives, regulators consider loads of sediment-associated contaminants such as mercury and PCBs, outflow to the Pacific Ocean, and deposition, erosion, and burial of contaminants in the bottom sediments of the Bay. Restoration project managers worry whether there is enough sediment to raise restoration sites high enough so vegetation can grow and improve the ecosystem.

A sediment budget is an accounting of sediment entering the Bay, being stored in the Bay, and exiting the Bay. This report presents three sediment budgets for water years 1955-1990, 1995-2002, and a 'normal' recent water year. Trends in the sediment budget are indicated by changes from the 1955-1990 budget to the present normal water year budget. Although seemingly a simple exercise, it is complicated by uncertainties and unknowns.

Sources and Sinks Must Add Up to Zero

Sediment enters the Bay with 1) drainage from the Central Valley watershed via the Delta, 2) drainage from local watersheds and tributaries, and 3) sand moving in from the Pacific Ocean along the bottom at the Golden Gate. Sediment leaves the Bay by either 1) flowing out as suspended sediment in the water column at the Golden Gate, 2) dredging and removal to ocean or upland dredged material disposal sites, 3) commercial sand mining, or 4) depositing in wetlands at elevations above mean tide. The sources can be thought of as income and the sinks as expenditures.

A very important tool for developing a sediment budget is the law of conservation of mass. We can neither create nor destroy mass, so the sources and sinks of sediment must add up to zero. Another way to express this is that sediment **inflow minus outflow must equal the change in storage**. If 3 kg of sediment come in and 2 kg go out, then 1 kg must have been stored (or deposited) in the Estuary. If 2 kg come in and 3 kg go out, then 1 kg must have been lost (or eroded) from the Estuary. Thus, if we know 2 of the 3 quantities (inflow, outflow, change in storage), we can calculate the third. If we are fortunate enough to know all 3, then we can use the law of conservation of mass to check our results.

What We Know About Inflow, Change in Storage, and Outflow

Inflow

Measurements of sediment entering the Bay are incomplete which means that these inflows must be estimated. Estimates of sediment entering the Bay from the Central Valley watershed were developed by McKee et al. (2002). These daily estimates were based on USGS continuous measurements of suspended-sediment concentration (Buchanan and Ganju 2004) and daily outflow estimates (California Department of Water Resources 1986) from 1995 to the present. The estimates are considered accurate to within ±17%.

A sediment budget is an accounting of sediment entering the Bay, being stored in the Bay, and exiting the Bay

Estimates of sediment inflow from local tributaries are based on measured and estimated streamflow and a USGS study of sediment inflow during the late 1950s (Porterfield 1980). The study established gages at which sediment discharge of several major local tributaries to the Bay was measured. For unmeasured tributaries, sediment discharge was estimated. Unfortunately, by 1973 all of the sediment gages in the Bay Area were discontinued due to lack of interest and funding. Some have been reestablished since 2000. To estimate sediment inflow from local tributaries to the Bay after the 1950s, the relationship between water flow and sediment discharge determined from the 1950s data is assumed to be valid and the 1950s methods of estimating the unmeasured sediment discharge are assumed to be valid. The Bay Area watershed has changed greatly over the past 50 years, so inflow estimates are uncertain. As we obtain more measured data from a wider range of hydrologic conditions, we can rely less on old data and the uncertainty will decrease. A back-of-the-envelope estimate is that sediment discharge from local tributaries is not known better than ±25%.

In addition to sediment entering the Bay from the Central Valley and local tributaries, sand appears to move from the Ocean into the Bay along the bottom of the Golden Gate. Much of the deposition in Central Bay was landward of the Golden Gate (Ogden Beeman and Krone 1992), where bottom sediments are sandy and bedforms indicate landward movement of sand in most of the cross section (Rubin and McCulloch 1979).

Change in Storage

Five comprehensive bathymetric surveys of the Bay have been conducted since 1850 to produce navigation charts showing the elevation of the Bay bottom. Bruce Jaffe and his USGS colleagues have analyzed the original data from these surveys to determine how the bathymetry has changed and the net change in sediment stored on the bottom of Suisun Bay (Cappiella et al. 1999), San Pablo Bay (Jaffe et al. 1998), and South Bay (Foxgrover et al. 2004). Bathymetric change information for Central Bay based on less accurate navigation charts is found in Ogden Beeman and Krone (1992). Change in storage calculations can only

Definitions

Budget
(for sediment in the Bay): a statement of whether you are losing or gaining money (gaining or losing sediment) in an account (Bay) for a definite period of time based on estimates of expenditures (outflow or "sinks") and income (inflow or sources).

The Bay
the water and bed sediment at mean tide from Mallard Island to the Golden Gate.

Sources
processes that result in transport of sediment into the Bay

Sinks
process that result in transport of sediment out of the Bay

be made up to the date of the latest bathymetric survey, which ranges from 1983 to 1990. These analyses determined the change in volume of sediment on the bottom of the Bay, which were then converted to mass.

Outflow

Sediment outflow at the Golden Gate is the most poorly characterized element of the sediment budget. Large plumes of sediment have been observed moving out into the Pacific Ocean from the Golden Gate when rivers flood into the Bay (Ruhl et al. 2001). Large currents, large water depths, moving sand waves on the bottom, large ocean waves, vessel traffic, fog, and strong winds make collecting data at the Golden Gate very difficult. Insufficient measurements exist to estimate this outflow for a sediment budget.

Sediment outflow to vegetated wetlands surrounding the Bay can be estimated by assuming that existing Bay wetlands maintain their elevation relative to sea level rise of 2.17 mm/year (Flick et al. 2003).

Dredged material disposal at upland and ocean sites removes sediment from the Bay and is a known quantity. Sand mining removes sand from the Bay for commercial purposes. Mining volumes have only recently been monitored but information exists (Hanson et al. 2004) to make very rough estimates of past volumes.

Sediment Budget for 1955-1990

Similar to the sediment budget developed by Ogden Beeman and Krone (1992) for 1955-1990, we estimate sediment inflow and change in storage. We use data and information that have become available since 1992, so the two budgets differ. Conservation of mass is then used to estimate the suspended sediment outflow.

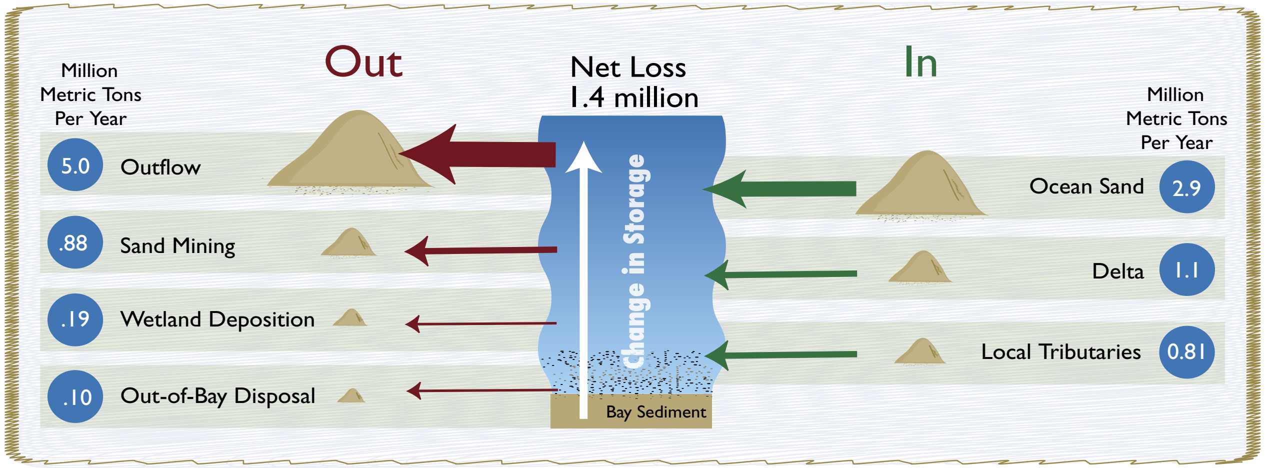


Figure 1. San Francisco Bay sediment budget for the period 1955-1990, in millions of metric tons per year. The areas of the sediment piles are proportional to their value in the budget. The size of the arrows also is proportional to budget values. The largest quantities are the outflow to the Ocean and inflow of ocean sand along the bottom. The uncertainty of the local tributary inflow is ±25 % and the uncertainty of the Delta inflow is ±17%. The other major sources of uncertainty are change in storage in Central Bay, sand inflow from the ocean, and sand mining. **The Bay experienced an average net loss of 1.4 million metric tons during this period.**

To estimate sediment inflow from 1955-1990, a relationship was established between Delta outflow (CDWR 1986), suspended-sediment concentration (SSC) measured by USGS at Freeport on the Sacramento River (Wright and Schoellhamer 2004), and suspended-sediment fluxes estimated by McKee et al. (2002). Sediment inflow from local tributaries was assumed to equal the rate of sediment inflow estimated by Porterfield (1980) from 1909-1966. The quantity of sand entering the Bay along the bottom of the Golden Gate was assumed to equal the sum of deposition in Central Bay and sand mining. A rough calculation of sand transport based on an empirical formula, velocity predictions, and sediment properties at the Golden Gate was 40% of this value, which given the uncertainties and assumptions, is reasonably close.

The change in storage was determined from annual rates (Cappiella et al. 1999, Foxgrover et al. 2004, Jaffe et al. 1998, Ogden Beeman and Krone 1992).

Ocean and upland dredged material disposal and a rough estimate of sand mining were used. Conservation of mass was used to estimate the outflow of suspended sediment at the Golden Gate.

The resulting sediment budget is presented in **Figure 1**. The largest quantities are the outflow to the Ocean and inflow of ocean sand along the bottom. The uncertainty of the local tributary inflow is ±25 % and the uncertainty of the Delta inflow is ±17%.

The other major sources of uncertainty are change in storage in Central Bay, sand inflow from the ocean, and sand mining.

Sediment Budget for 1995-2002

Estimating the sediment budget for 1995-2002 is more difficult because two of the three basic elements of the budget, storage and outflow, are not known for this period. Basically, we can estimate sediment inflow but we do not know if this new sediment deposits on the bed or flows out of the Bay. If the Bay is eroding, we do not know by how much.

To overcome this problem, we used a numerical model that is calibrated to the 1955-1990 period and applied to 1995-2002. We started with the Uncles and Peterson (1995) salinity model. The model uses 100 boxes to represent the Bay and calculates an average daily salinity for each box. Inflow from the Delta, local tributary inflow, salinity stratification, and the spring/neap tidal cycle are all included in the model.

We added model elements describing sediment movement: deposition, erosion, wind waves, sediment inflow from the Delta and local tributaries, deposition in wetlands, and sediment storage or loss from the Bay bottom (Lionberger 2003). The model deposits or erodes sediment from the bed and moves sediment out the Golden Gate. Model coefficients for deposition, erosion, and wind waves were calibrated so that for the period 1955-1990 the model re-created the observed change in bed storage for the estimated sediment inflow. We assumed that the same coefficients were applicable to the 1995-2002 period. Bathymetric change in Central Bay is assumed to be caused by sand entering at the Golden Gate which the model does not simulate, so the model has no net change in sediment storage in

In recent years the annual loss of sediment from the Bay has increased substantially

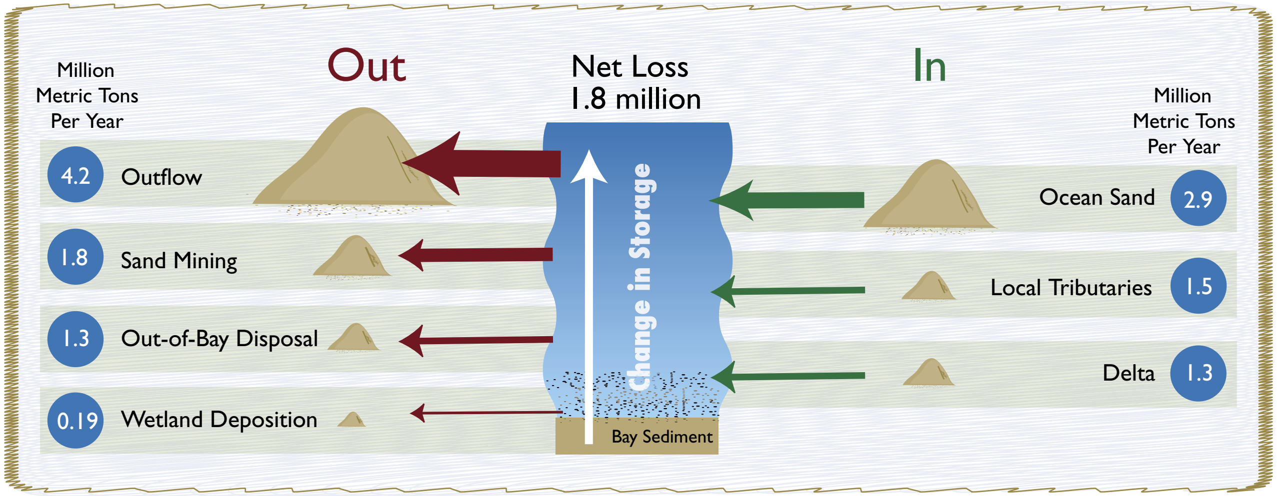


Figure 2. San Francisco Bay sediment budget 1995-2002. While this is the estimated actual budget for 1995-2002, average water flow into the Bay during this period was higher than for 1955-1990, making the two budgets not directly comparable. Data in millions of metric tons per year. The areas of the sediment piles are proportional to their value in the budget. The size of the arrows also is proportional to budget values. **The annual net loss of sediment from the Bay during this period was 1.8 million metric tons.**

Central Bay. The model was then run for this period using the estimated sediment inflow. Because of its large boxes, daily time step, and rough approximation of deposition and erosion, model results are uncertain. We do have better information on sediment inflow from the Delta and sand mining, but overall the 1995-2002 sediment budget (**Figure 2**) is probably more uncertain than the 1955-1990 sediment budget. The model does not simulate sand entering the Bay, out-of-Bay dredged material disposal, and sand mining. These quantities were calculated separately as described previously.

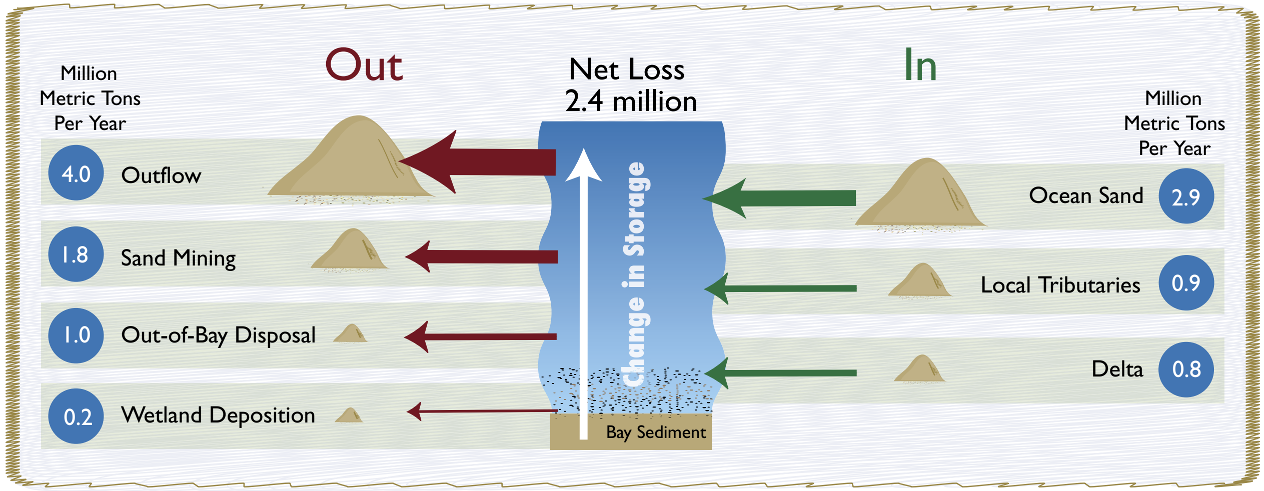


Figure 3. San Francisco Bay sediment budget for a normal water year during 1995-2002. There are some notable differences between the 1955-1990 budget (Figure 1) and this normal year 1995-2002 sediment budget. Sediment inflow from the Delta has decreased during the second half of the 20th century. Sediment inflow from local tributaries appears to now be greater than from the Delta, but this finding is within the uncertainty of the estimates. Sand mining and out-of-Bay dredged material disposal have increased. **The net result is that the adjusted annual loss of sediment from the Bay has increased substantially.** Data in millions of metric tons per year. The areas sediment piles are proportional to their value in the budget. The size of the arrows also is proportional to budget values.

Sediment Budget for a Normal Water Year 1995-2002

The average water flow into the Bay from the Delta was 795 m^3/s from 1955-1990 and much higher, 987 m^3/s, from 1995-2002. Higher water flows carry larger amounts of sediment into the Bay. Thus, it is not appropriate to compare the two budgets directly because 1995-2002 was wetter, and had much more sediment inflow. If water years 1995 and 1998 are removed, the average flow is 761 m^3/s and the flow duration curve, or how often a given flow occurs, is very similar to 1955-1990. Removing these years results in a sediment budget (**Figure 3**) that can be directly compared to the 1955-1990 budget.

There are some notable differences between the 1955-1990 (**Figure 1**) and normal year 1995-2002 (**Figure 3**) sediment budgets. Sediment inflow from the Delta decreased during the second half of the 20th century (Wright and Schoellhamer 2004). Sediment inflow from local tributaries appears to now be greater than from the Delta, but this finding is within the uncertainty of the estimates. Sand mining and out-of-Bay dredged material disposal have increased. The net result is that the annual loss of sediment from the Bay has increased substantially.

Implications for Dredgers, Regulators, and Restoration Planners

Just as determining a family budget leads to evaluating income and expenditures of individual family members, these sediment budgets have implications for dredgers, regulators, and restoration planners. The decrease in sediment inflow has contributed to a decrease in maintenance dredging. The amount of sediment disposed of outside the Bay has increased by a factor of 10. During 1995-2002, 25% of dredged sediment was disposed in the Ocean, 22% was disposed upland, and 53% was disposed in the Bay. Given decreasing sediment inflow, increased ocean disposal, and increased future 'demand' from restoration projects, finding a way to shift disposal from the ocean back to the Bay could provide ecological benefit and decrease dredging costs.

Sand mining removes almost twice as much sediment from the Bay as dredging. Sand mining has been ignored in previous sediment budgets because there was no information to estimate it. About 80% of sand mining is from Central Bay (Hanson et al. 2004), so whether or how sand mining would affect restoration projects in the Delta or South Bay is not clear.

For water quality regulators, the decrease in sediment inflow from the Central Valley increases the relative importance of local watersheds as a source of sediment and associated contaminants. Most of the Bay is eroding which mobilizes legacy contaminants from the sediment bed. The change in bed storage is a balance between sediment inflow and the erosive forces of tides and wind, which are fairly constant from year to year. So if sediment inflow continues to decrease, erosion and mobilization of legacy contaminants should continue. Even if sediment inflow were to remain constant, the Bay would continue to erode until a new balance between sediment inflow and erosive forces is reached. Thus, the Bay bottom will continue to be a source of contaminants.

The elevation of restoration sites is usually low enough that deposition is needed to build the land surface up to a level where plants can grow. Planners need to consider that the Central Valley is no longer the primary source of sediment to the Bay and local tributaries are of approximately equal importance. Wetland deposition in the budgets is relatively small but would increase as large tracts of land are opened up to tidal action by restoration projects. While the entire Bay is eroding, the large restoration projects planned for the Delta and lower South Bay are located where there is presently net deposition. The questions confronting restoration planners are how quickly sediment would deposit on a restoration site, how large of a restoration can be supported by the sediment supply, and will capturing a large amount of sediment increase erosion elsewhere?

Restoration projects could increase erosion and mobilization of legacy contaminants. Disposing less dredged material in the Ocean could decrease erosion and the demand for sediment from the restoration projects. Dredging, restoration, and water quality management are all closely connected through the cycling of sediment in the Bay.

Future Steps

The Clean Estuary Partnership (CEP) is supporting documentation of the sediment transport model by USGS and continued application of the model to describe PCB fate in the Bay. The sediment model can also be used to develop budgets for sediment-associated contaminants other than PCBs. The Regional Board can use sediment budgets to help develop TMDLs for sediment-associated contaminants. The South Bay Salt Pond Restoration Project (see article on page 72) is collecting new bathymetry data for South Bay that will be analyzed by USGS and provide validation of the recent sediment budget for South Bay. USGS and the project consultant team are studying how restoring the South Bay salt ponds would affect the sediment budget of South Bay. To improve the accuracy of sediment budgets, additional measurements of sediment inflow, additional measurements of bed sediment density, bathymetric analysis of Central Bay, and new bathymetric surveys in Suisun, San Pablo, and Central Bays are needed. Also needed, but less feasible, are measurements of sediment outflow.

Acknowledgements

This work is supported by the U.S. Army Corps of Engineers as part of the Regional Monitoring Program, San Francisco Regional Water Quality Control Board, California State Coastal Conservancy, and the U.S. Geological Survey Priority Ecosystem Science and Federal/State Cooperative Programs. The Clean Estuary Partnership is supporting documentation of the numerical model used to develop the 1995-2002 sediment budgets.

The CALFED Bay-Delta Program: A Major Investment in Improving Water Quality in the Estuary

Donna Podger (dpodger@calwater.ca.gov), Margaret Gidding, and Dennis Bowker - California Bay-Delta Authority
Swee J. Teh, Serge Doroshov, Javier Linares - University of California, Davis

Key Points

- CALFED is investing nearly $200 million in 227 projects to protect water quality in the Bay-Delta and its watershed
- Three CALFED program elements (Watershed Management, Ecosystem Restoration, and Water Quality) address water quality issues
- Due to the potential for habitat restoration to increase mercury exposure in humans and wildlife, CALFED has developed a Mercury Strategy and provided more than $30 million for projects to implement the Strategy
- Research funded by the Ecosystem Restoration Program (ERP) suggests that selenium may be causing deformities, growth impairment and mortality in early life-stages of Sacramento splittail and white sturgeon
- The Watershed Management Program is funding many projects in the Bay-Delta to build the capacity for local watershed stewardship by citizens groups, schools, planners, landowners, businesses, and elected officials

Introduction

In its fifth year of implementation, the CALFED Bay-Delta Program (**Figure 1**) is a multi-billion dollar joint state and federal effort to improve the quality and reliability of California's water supplies while restoring the Bay-Delta ecosystem. The success of this 30-year Program hinges on addressing multiple objectives simultaneously in a balanced manner. Protecting and enhancing water quality in the Bay-Delta and its watershed is a significant part of this approach, as evidenced by the nearly $200 million that is being invested in this issue alone.

Activities of three CALFED Program elements— Ecosystem Restoration, Water Quality, and Watershed Management—each with a different focus and approach, collectively support 227 projects that contribute to improved water quality throughout the CALFED solution area (**Figures 2 and 3**). The activities and accomplishments of each program are described below, followed by some more detailed examples of projects supported by the Ecosystem Restoration Program and the Watershed Management Program. The funding for many of these projects came from propositions supported by California voters (Proposition 204 in 1996, Proposition 13 in 2000 and Proposition 50 in 2002).

The **Water Quality Program** (WQP) is investing in projects to improve water quality from source to tap for the more than 22 million Californians that receive their

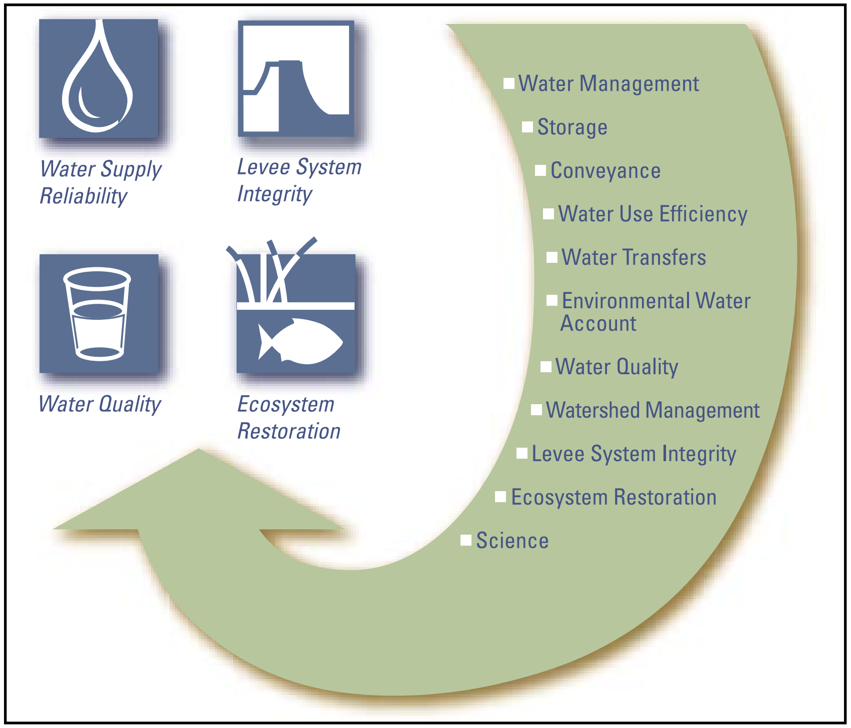


Figure 1. The CALFED Program has 4 resource management objectives that are supported by the activities of 11 program elements and the state and federal agencies implementing the CALFED program.

water from the Bay-Delta Estuary and tributaries. The WQP has invested more than $76 million in 60 projects to improve drinking water quality, ranging from source improvement, regional water investigations and exchanges, conveyance improvements, treatment demonstrations and research across the state. In the Bay area, the WQP has provided financial support to several projects, including source water blending and exchanges, investigating treatment options, and watershed management for the North Bay and South Bay aqueducts. The main constituents of concern addressed by the WQP are those that degrade drinking water quality, including disinfection byproduct precursors (e.g., bromine and organic carbon), pathogens, nutrients, salinity, and boron.

One underlying premise of the **Watershed Management Program** is to help integrate a watershed approach into the CALFED Program as a whole. It does that by empowering a diverse set of stakeholders to collaborate and work with CALFED agencies in order to create partnerships that help attain maximum benefits for the Bay-Delta Watershed and its communities. The goals of the Watershed Program are to provide assistance—both financial and technical—for watershed activities that help achieve the mission and objectives of the CALFED Program, and to promote collaboration and integration among local watershed programs. The Watershed Program also acknowledges that watershed management comprises more than just projects. It includes such varied issues as land use decision-making, development of watershed assessments and management plans, monitoring, education and outreach, and capacity building. The Watershed Program has provided support for 112 projects for more than $52 million that contribute to watershed management goals. More than 95% of those projects contribute to improving water quality and water supply reliability, either directly by implementing projects that reduce or prevent sources of pollutants, or indirectly by fostering local stewardship of the watershed, providing funds for watershed assessments and management plans, and providing for outreach and education within local communities. A sampling of watershed projects in the Bay area is listed in later sections of this article, along with descriptions of three local projects supported by the Watershed Program.

The **Ecosystem Restoration Program** (ERP) is designed to maintain, improve, and increase aquatic and terrestrial habitats and improve ecological functions in the Bay-Delta to support sustainable populations of diverse and valuable plant and animal species. The ERP is also designed to achieve recovery of at-risk species dependent on the Delta and Suisun Bay, and support the recovery of at-risk species in San Francisco Bay and in the watershed above the Estuary. Improving water and sediment quality to support a healthy and diverse ecosystem and to reduce toxic impacts to aquatic life, wildlife and humans is one of the 6 goals of the ERP. Overall, the ERP has provided more than $500 million in support for 415 projects to improve the health of the ecosystem. Of that total, 55 projects, for approximately $67 million dollars are focused on research, monitoring, and source control projects to reduce impacts to aquatic organisms from toxic chemicals and oxygen depletion, as well as ways to address chemicals that bioaccumulate in the food chain and may affect people and wildlife who consume fish. The main constituents of concern for the ERP are mercury, low dissolved oxygen, pesticides, selenium and other constituents that may cause toxicity or bioaccumulation in aquatic organisms. A broad range of water quality projects have been supported by the ERP, including research to investigate sources and cycling of mercury and selenium, monitoring of contaminants in water, sediment and biota, studies on ecological effects of contaminants, projects to reduce sources of pollutants such as agricultural drainage and urban stormwater runoff, and public outreach and education on fish contamination issues.

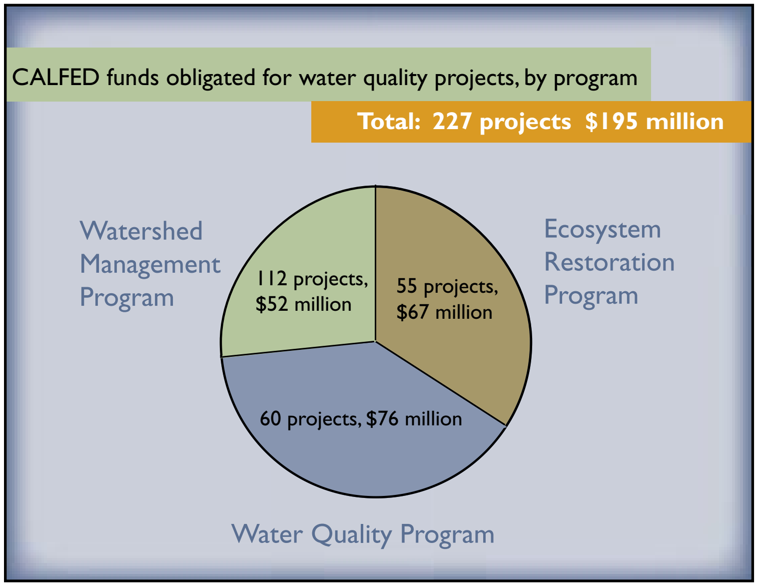


Figure 2. The CALFED Program objective to improve water quality for all beneficial uses is supported by three CALFED Program elements: Watershed Management, Ecosystem Restoration, and Water Quality.

Mercury is one of the greatest water quality concerns in the Bay-Delta due to the legacy of contamination from gold and mercury mining and the potential for habitat restoration to increase mercury exposure to humans and wildlife. To address this challenging issue, the CALFED Science Program funded the development of a mercury strategy: "*Mercury Strategy for the Bay-Delta Ecosystem: A Unifying Framework for Science, Adaptive Management, and Ecological Restoration*" by a team of national mercury experts with input from local scientists, agency staff and the public (Wiener et al. 2003). The Strategy describes the current state of the knowedge related to mercury and provides a framework for future investigations. In 2004, the Strategy was formally adopted by the California Bay-Delta Authority, and agency and Authority staff will be working to develop an implementation workplan.

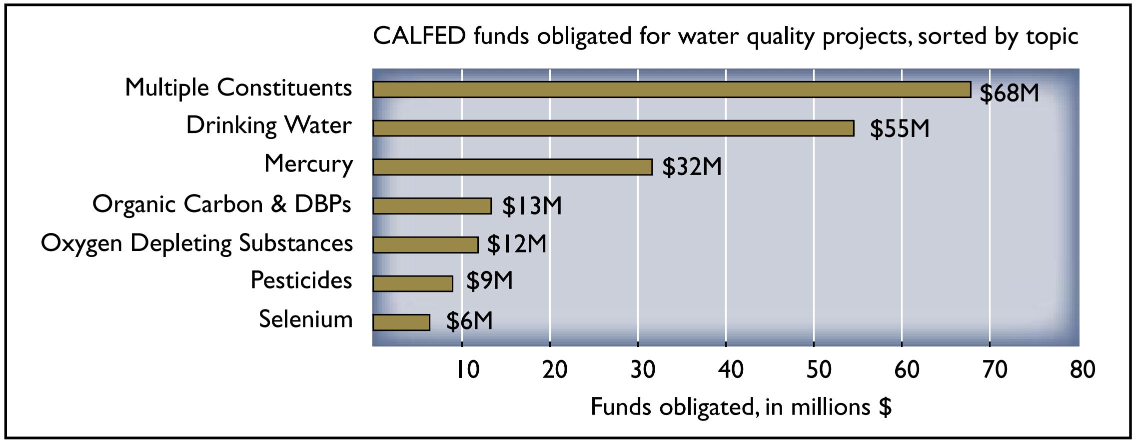


Figure 3. About one-third of the projects funded address multiple constituents that may be affecting water quality. Substantial funds have also been provided to support projects to improve drinking water quality, and reduce effects of mercury, dissolved oxygen depletion, and pesticides.

The Strategy describes three basic management approaches to address the problem:

- identify and reduce bioavailable sources of mercury,
- monitor and provide information to the public on how to reduce exposure to methylmercury from eating fish, and
- investigate landscape management options to reduce methylmercury production and exposure in the watershed.

Many agencies and groups are working on this problem, and will be collectively implementing the recommendations in the Mercury Strategy. To date, the CALFED program has provided more than $30 million for projects to implement the Strategy, including research on sources and cycling of mercury, evaluating ecological effects, water and tissue monitoring, and public outreach and education.

An Example of ERP Research to Improve Water Quality: Ecological Effects of Selenium

Selenium is a priority contaminant in the Estuary as reflected in its inclusion on the Clean Water Act Section 303(d) list of impaired waterbodies for the Bay. Selenium is primarily a concern because it accumulates to concentrations in the food web that can pose health risks to humans and wildlife. Selenium studies funded by the ERP provide an example of how CALFED agencies are funding projects that generate information that is critical to understanding water quality concerns and evaluating management actions.

Selenium is a naturally occurring element in geologic formations of the Central Valley. Irrigated agriculture can increase selenium loads into waterways when it

CALFED has provided more than $30 million to implement a Mercury Strategy for the Bay-Delta

drains from the soil into surface waters. Other sources include refineries, wastewater discharges and natural weathering processes. Once in the aquatic environment, complex reactions determine the form of selenium, which in turn determines how it cycles through the environment and enters and bioaccumulates in the food web. In general, bivalves (clams, mussels) in San Francisco Bay have elevated selenium compared to reference sites, and the invasive clam *Potamocorbula amurensis* has particularly high concentrations. Because the concentrations increase up the food chain, predator species are of special concern.

Selenium is an essential element for diets, but problems may arise because the window between the required concentration and the toxic concentration is narrow (Hodson and Hilton, 1983). Reproductive failure and deformities in developing young fish or birds are the most common effects of excessive selenium exposure. In fish, the selenium can be passed from the mother in the egg yolk and deformities occur while the larval fish are dependent on the yolk sac for nourishment. The deformities do not always cause direct mortality but they increase the probability that the juvenile will not survive to adulthood for various reasons, including predation. Described below are two studies funded by ERP to investigate the reproductive and developmental effects (deformities) of selenium on two key species: Sacramento splittail and white sturgeon.

Selenium and Sacramento Splittail

Sacramento splittail (*Pogonichthys macrolepidotus*) is a native fish species that was once widespread in the Central Valley and Estuary, but whose distribution and abundance has been greatly reduced due to a variety of factors. Sacramento splittail adults live in the brackish waters of the Estuary, moving upstream to spawn on seasonal floodplains in the early spring. Their diet consists mainly of benthic invertebrates and a recent study has shown that they are changing their diet to consume more of the invasive clam *Potamocorbula*, which is high in selenium (Brown and Luoma, 1995; Linville et al., 2002). Hence, there is concern that selenium bioaccumulation and exposure may be causing reproductive problems or birth defects in the larval fish. A research team at University of California, Davis (Swee J. Teh, Xin Deng, Don-Fang Deng, Foo-Ching Teh, Silas S.O. Hung) has conducted a series of lab experiments to investigate the effects of dietary selenium on various life stages of the Sacramento splittail.

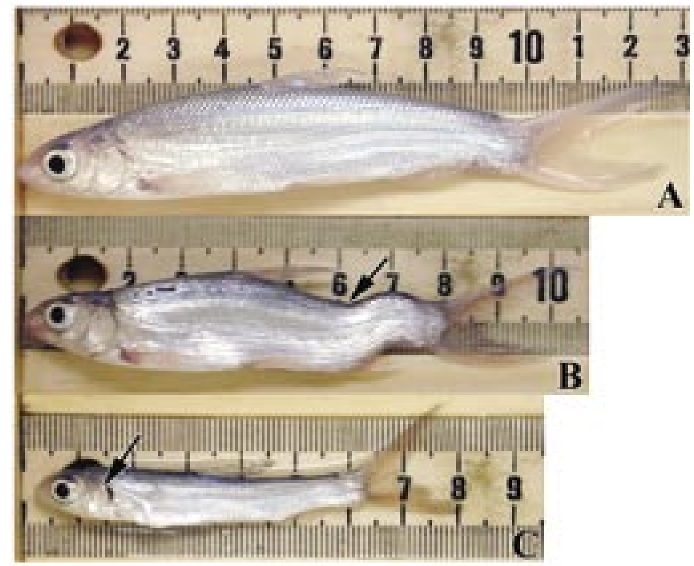


Figure 4. Laboratory studies indicate that dietary selenium exposure is causing deformities, growth impairment and mortality to Sacramento splittail in this watershed, which may affect the long-term growth and survival of the species.

Splittail eggs were exposed to different levels of selenium to simulate effects of maternal transfer of selenium. One-quarter to one-third of the eggs that had been exposed to selenium hatched into larval fish with deformities such as loss of tail or curvature of the spine. Even though there was no difference in hatching success between the groups, it is likely that the deformed larval splittail would not survive to adulthood in the natural environment (Teh et al., 2002). Groups of juvenile splittail were also exposed to selenium through their diet. After 9 months of exposure, the two highest exposure groups (26 to 57 mg/kg) had higher mortality and slower growth than the other groups. Five of the groups with lower selenium exposure concentrations had significant facial and skeletal deformities (1.4 to 12.6 mg/kg), but surprisingly, the deformities were not seen in the higher exposure groups. Fish in the two highest exposure groups also had abnormal swimming behavior; swimming belly up or lying motionless on the bottom of the tank (Teh et al., 2004). When adult Sacramento splittail were exposed to high levels of dietary selenium over a 6-month period, there were no significant differences in growth or mortality, although some of the adults in the highest exposure group did lose equilibrium after a few months of exposure.

The dietary exposures evaluated in the lab were within the range experienced by wild splittail. The photos (**Figure 4**) show Sacramento splittail with different exposures. **A** was exposed to very low levels of selenium in the diet. **B** had deformities that were typical in the mid-range exposure groups, and **C** had slower growth due to higher exposure to dietary selenium, but deformities were not as prevalent (Teh et al., 2004).

Summarizing findings from these experiments for Sacramento splittail, embryos, developing larvae, and juvenile fish are most sensitive to selenium exposure with effects including behavioral changes, deformities, reduced growth, histological lesions in the liver, kidney and ovaries, and mortality. However, exposures and effects did not follow a typical "dose-response" type of relationship, demonstrating that chronic selenium toxicity is a complex interplay between dose and length of exposure. Deformities and organ damage became significant in the groups of juvenile splittail that were fed diets at or above 6.6 mg/kg for 9 months, while effects such as reduced growth or mortality were not significant except at higher doses (26 and 57.6 mg/kg). Adult splittail were not as sensitive to effects of selenium exposure as juveniles. These dietary exposure levels are within the range of tissue concentrations in the prey of splittail, indicating that there is potential that dietary selenium exposure is causing deformities, growth impairment, and mortality to Sacramento splittail in this watershed, which may affect the long-term growth and survival of the species.

Selenium and White Sturgeon

Another research group at the University of California, Davis (Javier Linares, Regina Linville, Joel Van Eenennaam, Serge Doroshov) has been investigating the effects of selenium on another important species - white sturgeon (*Acipenser transmontanus*). White sturgeon are large, long-lived fish that are primarily found in the northern San Francisco Bay and Delta and migrate into the Sacramento River to spawn. Selenium exposure is a concern for sturgeon because their diet often consists of large quantities of *Potamocorbula*, which accumulates high concentrations of selenium. There is also concern for the reproductive success of the sturgeon because they may pass selenium into the egg yolk, which may make the embryos and yolk-sac larvae susceptible to developmental defects or mortality (Linares et al., 2004).

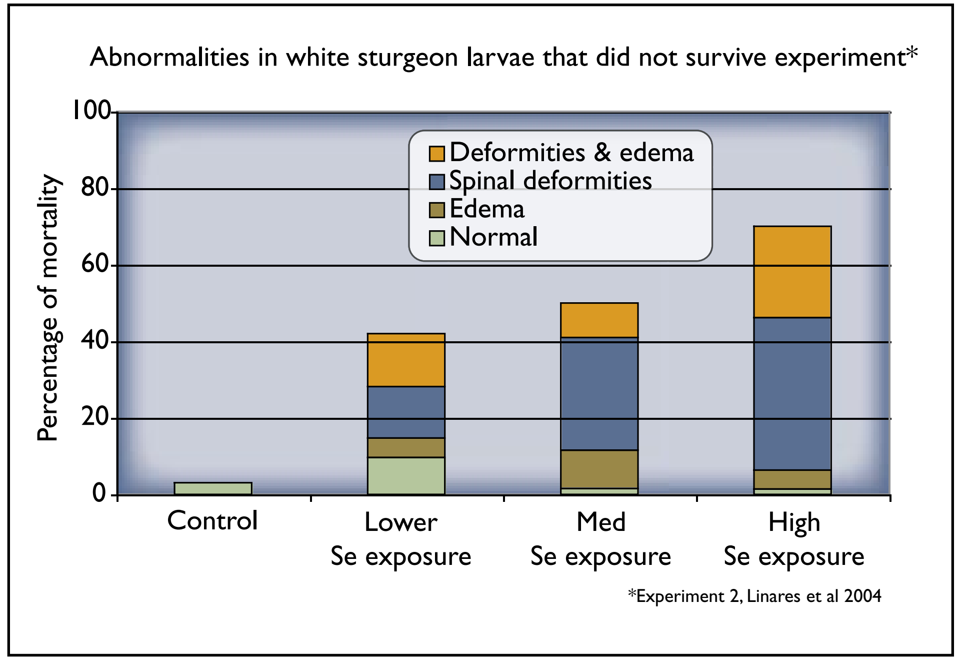


Figure 5. It is likely that white sturgeon in the Estuary have high enough exposure to selenium to be causing deformities in developing young, at least in some offspring, potentially affecting reproductive output in this valuable species. Groups of white sturgeon larvae that were exposed to higher selenium concentrations (microinjection of yolk-sac larvae) had more mortality and more deformities and edema (swelling of tissue) (Linares, et al., 2004). The exposures tested were similar to those occurring in wild sturgeon in the Estuary.

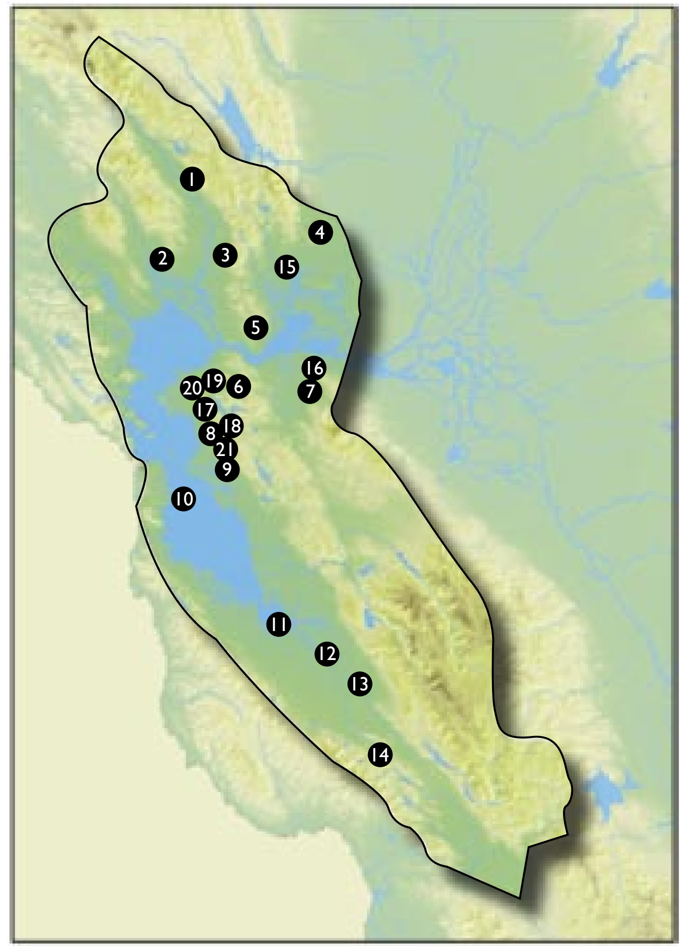
One part of the UC Davis study was to investigate selenium concentrations in the tissues of white sturgeon from the Bay and Delta from 2002 to 2004. Forty-six fish, ranging in size from 68 to 107 cm, and in age from 4 to 18 years, were analyzed for selenium. These were mainly sub-adults that had not reached sexual maturity. The average concentrations of selenium in the kidney, liver, muscle and gonads approached the levels that have been associated with toxicity and reproductive failure in other fish species (Linares et al., 2004). The selenium concentrations generally increased with size and age of the fish. This study found lower average levels than a previous study, but that may be due to the relatively young age of the fish, as well as possible seasonal variability or differences in feeding patterns (Linares et al., 2004).

Another part of the study included laboratory experiments where the researchers exposed developing larvae by microinjecting yolk-sac larvae with a selenium solution. Mortality and deformities of the white sturgeon larvae increased as selenium exposure increased (**Figure 5**). The selenium exposure caused deformities such as edema and spinal deformities, with a sharp rise in the percentage of abnormalities and mortality at tissue concentration above 16 ug/g. This is similar to toxic thresholds found in other studies of selenium effects on fish eggs and larvae. In the 1990s, eggs from six female sturgeon caught in the Sacramento River ranged from 8 to 29 ug/g of selenium (Linares et al 2004). Thus it is likely that white sturgeon in this Estuary have high enough exposure to selenium to be causing deformities in developing young, at least in some offspring, potentially affecting reproductive output in this valuable species.

These two studies suggest that selenium concentrations in the Bay food web may be high enough to cause reduced survival of early life stages of two important fish species in the Estuary. In other words, the studies provide cause for concern that selenium is impacting beneficial uses related to preservation of estuarine and wildlife habitat. Management actions that increase selenium concentrations in the Bay would be likely to increase health risks to these species. More field studies are needed to evaluate the extent of selenium bioaccumulation and how it is affecting reproduction in white sturgeon, Sacramento splittail, and other species of concern.

Two studies suggest that selenium in the food web may be high enough to cause reduced survival of early life stages of fish

Figure 6. The Watershed Management Program has provided support to 21 projects in the Bay Area that contribute to improvements in water quality.



1. Napa River Watershed Mapping Partnership *(San Francisco Bay Regional Water Quality Control Board)*
2. Sonoma Creek Watershed Conservancy *(Sonoma Ecology Center & others)*
3. Stewardship Support and Watershed Assessment in the Napa River Watershed *(Napa County Resource Conservation District)*
4. Lagoon Valley Watershed Restoration *(City of Vacaville)*
5. Citizen Involvement and Regional Outreach Program *(Aquatic Outreach Institute)*
6. Contra Costa County Watersheds Atlas and Creek Restoration Strategy *(Contra Costa County Community Development Dept.)*
7. Walnut Creek Watershed *(Contra Costa Flood Control District & Water Conservation District)*
8. Codornices Creek Watershed Restoration Action Plan *(Urban Creeks Council)*
9. Partnership for Sub-regional Watershed Forums and a Watershed Center *(Merritt College Environmental Program)*
10. Yosemite Watershed Restoration Assessment Project *(Bayview-Hunters Point Community Advocates / ARC Ecology)*
11. San Francisquito Creek Watershed Enhancement Program *(San Francisquito Watershed Council, a project of Acterra)*
12. Upper Guadalupe River Tributary Monitoring Program and Pilot Restoration Project *(Guadalupe Coyote Resource Conservation District)*
13. Stewardship Plans for West Valley, Guadalupe, and Lower Peninsula Watershed areas of Santa Clara County *(Santa Clara Valley Water District)*
14. Almaden Reservoir Watershed Restoration Project *(Santa Clara Valley Water District)*
15. Suisun Creek Watershed Program *(California Sport Fishing Alliance)*
16. Mt. Diablo Creek Watershed CRMP Program *(Contra Costa Resource Conservation District)*
17. Baxter Creek Restoration *(City of El Cerrito)*
18. Codornices Creek Watershed Restoration Actions, Stage 2 *(Urban Creeks Council)*
19. A WRAPP (Watershed Restoration Action and Priority Plan) for Wildcat/San Pablo Creeks *(Urban Creeks Council)*
20. Enhancing Local Capacity in N. Richmond and Parchester Village to Manage and Restore Lower Rheem Creek Watershed *(National Heritage Institute)*
21. Oakland Releaf Watershed Protection Program *(Oakland Releaf)*

Watershed Management Projects in the Bay Area

Overview

The Watershed Management Program has supported efforts to improve water quality in the Bay Area by providing financial support to 21 projects. These projects are employing a wide range of approaches such as planting trees in West Oakland, restoring riparian habitat in Almaden reservoir and Codornices Creek, and providing support for watershed assessment and planning in Contra Costa County, the Napa River, Lower Rheem Creek, Suisun Creek, and Mt. Diablo Creek. Other activities include data collection and database development, outreach and education, and monitoring. The following three projects are examples of efforts that are taking a watershed management approach. For more information on any of the projects, see the website: www.baydeltawatershed.org.

Yosemite Watershed Restoration Assessment Project

The Watershed Program has provided financial support to the Bayview-Hunters Point Community Advocates and ARC Ecology to conduct an assessment of the Yosemite Watershed that may serve as a model for other urban watersheds. The Yosemite Creek/Slough/South Basin ecosystem is located in the heavily urbanized Bayview-Hunters Point community in San Francisco. It is a low-income community with a long history of environmental justice issues. The Watershed has experienced significant loss of ecological function and habitat for aquatic and avian species, and presents a health hazard for those who use it for recreation and subsistence. In the first phase of a long-term effort to restore this urban watershed, this project is conducting a community-based watershed assessment to identify the water quality and ecological impacts on Yosemite Creek/Slough. The assessment involves a wide variety of community-based activities that include identifying conditions that can have an impact on water quality, evaluating opportunities for restoring surrounding wetlands, creating a watershed planning process, and offering training, education and capacity-building to many different community groups. Projects such as these will help improve the quality of life for the Bayview-Hunters Point community over time.

There are no quick fixes for problems like mercury, selenium, and many other contaminants in the environment

Partnership for Sub-Regional Watershed Forums and a Watershed Center

The Watershed Program has provided funds for the Merritt College Environmental Program to create a prototype watershed center that lays the groundwork for expansion into a network of locally led watershed centers throughout the Bay Area. This prototype serves Alameda County. The goal of this project is to increase awareness and build the capacity for local watershed stewardship management by citizens groups, schools, planners, landowners, businesses, and elected officials. These groups already execute or oversee many small projects that cumulatively affect streamflow, water quality, habitat, and human use benefits. Project goals include: developing databases and conducting watershed forum discussions on policy, science, education, and participation; creating a watershed center and subset of riparian centers; building watershed group organizational capacity; including underrepresented communities in watershed planning; and developing a field program in watershed awareness and organization, monitoring, project implementation, fire safety, and watershed vegetation management.

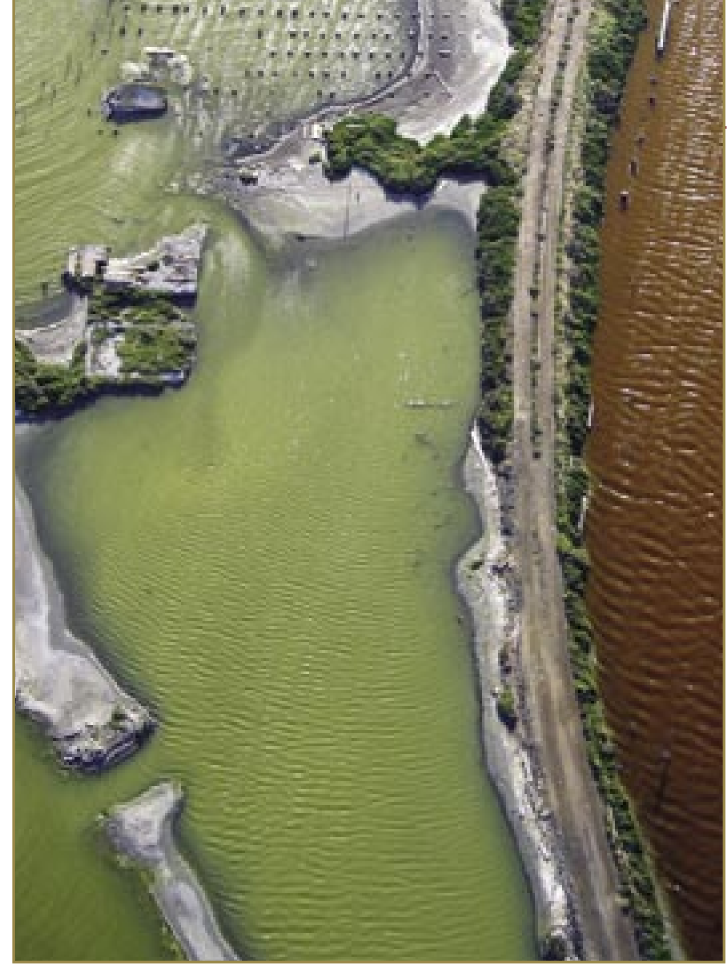
Stewardship Support and Watershed Assessment in the Napa River Watershed

The Watershed Program has provided funds for the Napa County Resource Conservation District to work with two watershed communities to conduct baseline watershed assessments, create adaptive watershed management plans, and promote community-based watershed monitoring efforts to address a broad range of ecological, biological, and social values in the watersheds. Sulphur Creek and Carneros Creek are important tributaries of the Napa River. Through facilitating management of these two watersheds, the project is building a common base of understanding by assessing the physical, ecological, and social conditions of the watersheds and, using a scientific approach, defining priorities for restoration that are socially acceptable. In so doing, the project will improve the connection between watershed processes and land management in the Sulphur Creek and Carneros Creek Watersheds. Project goals include: carrying out physical and biological watershed assessments that involve community group volunteers in data gathering; incorporating stakeholders in writing watershed management plans that include conservation, maintenance, and restoration strategies based on the assessments; and sharing data with multiple entities, including agencies interested in comparative analyses and linked projects

These CALFED projects, and many more like them, are underway to help CALFED agencies understand what is happening in the Estuary and to help guide policy decisions using the latest scientific information to improve the ecosystem and water quality for all living creatures. The Program elements—Ecosystem Restoration, Water Quality, and Watershed Management—have different approaches, but the overall CALFED Program objectives can only be achieved by funding all of the different approaches simultaneously. The CALFED Program is a 30-year Program—there are no quick fixes for problems like mercury, selenium, and many other contaminants in the environment. By building a scientific and organizational foundation, CALFED agencies will continue to improve water supply reliability and water quality for urban, agricultural and environmental purposes across the state.

Water Quality Concerns Related to the South Bay Salt Pond Restoration Project

Jay A. Davis (jay@sfei.org), Letitia Grenier, and Robin Grossinger, San Francisco Estuary Institute



Key Points

- In the most ambitious tidal wetland restoration project ever on the west coast of North America, the South Bay Salt Pond Restoration Project plans to restore 16,500 acres of San Francisco Bay salt ponds to tidal marsh
- Water quality concerns related to wetland restoration projects include the potential for increased mercury accumulation in the food web of the marshes and the Bay, legacy sediment pollution at specific restoration sites, accelerated erosion and recirculation of polluted Bay sediment, and the impacts of new inputs of pollutants
- Restoration projects should take an adaptive management approach, minimizing risk by taking actions based on existing knowledge while conducting the monitoring and research needed to assess and reduce negative impacts

Introduction

In the summer of 2004, the U.S. Fish and Wildlife Service lifted tide gates to release water from salt ponds formerly owned by Cargill Salt, marking the beginning of the most ambitious tidal wetland restoration project ever on the west coast of North America. Overall, the South Bay Salt Pond (SBSP) Restoration Project plans to restore 16,500 acres of salt ponds to tidal marsh: 15,100 in South Bay (**Figure 1**) and 1,400 along the Napa River in the North Bay. The salt ponds were purchased at a cost of $100 million in 2003. The objectives of the Project are to restore and enhance a mix of wetland habitats to support wildlife, to provide for flood management, to protect or improve water and sediment quality, and to provide public access and recreation opportunities in the highly populated and urbanized setting of San Francisco Bay. More information on the Project is available at http://www.southbayrestoration.org/.

The SBSP Restoration Project is just one of several ambitious wetland restoration projects underway throughout the Estuary. These projects are certain to be tremendously beneficial. However, significant concerns exist with regard to the potential impacts of the projects on water quality in the Bay, and with the potential impacts of Bay water quality on the projects. Tidal marshes are intimately connected to the open waters of the Estuary through exchange of water and sediment. Consequently, a process such as methylmercury production that is associated with wetland habitat could occur in the restored marshes and have a regional impact on water quality in the Bay. On the other hand, pollutants from the open waters of the Bay may also flow into tidal marshes and accumulate to problematic concentrations.

This article will describe the most significant water quality concerns relating to the SBSP Restoration Project. Similar concerns also surround other tidal marsh restoration projects in the Estuary. There is a distinct potential that these massive restoration projects could lead to or contribute to serious pollution problems in the restored marshes and the open

Note: This article summarizes a longer paper on this topic written for the South Bay Salt Pond Restoration Project. For more information contact Jay Davis: jay@sfei.org.

Astronaut photograph of the South Bay Salt Ponds. Image courtesy of the Image Analysis Laboratory, NASA Johnson Space Center.

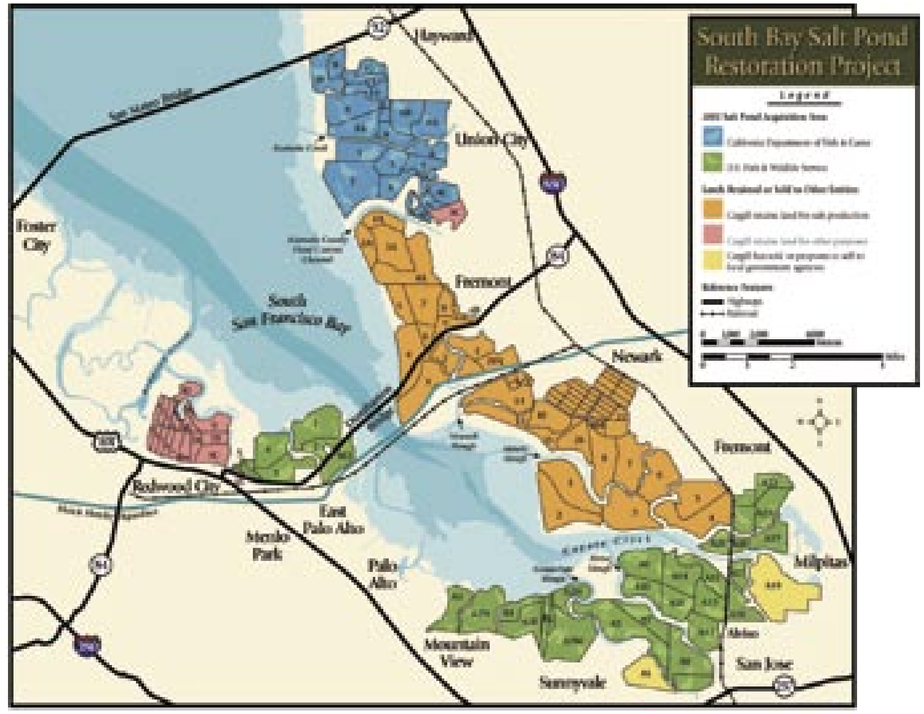


Figure 1. Over 15,000 acres of salt ponds are targeted for restoration in the South Bay. The restored marshes will almost completely encircle the Lower South Bay, making them likely to have a large influence on water quality in this region. From the SBSPRP website: http://www.southbayrestoration.org/

waters of the Bay. However, it is also possible that the water quality impacts will not be severe, especially if the projects move forward in a manner that takes these concerns into consideration.

These concerns call for an adaptive management approach to implementing the Project. An adaptive management approach entails cautiously proceeding with actions of limited scope commensurate with existing knowledge, seizing opportunities to obtain better information through scientific study of the actions taken, and modifying future actions based on the new information. Such an approach will allow the project to reap the substantial anticipated benefits, while minimizing the adverse impacts on water quality. Recommendations on how to provide the scientific foundation needed for adaptive management are presented at the end of this article.

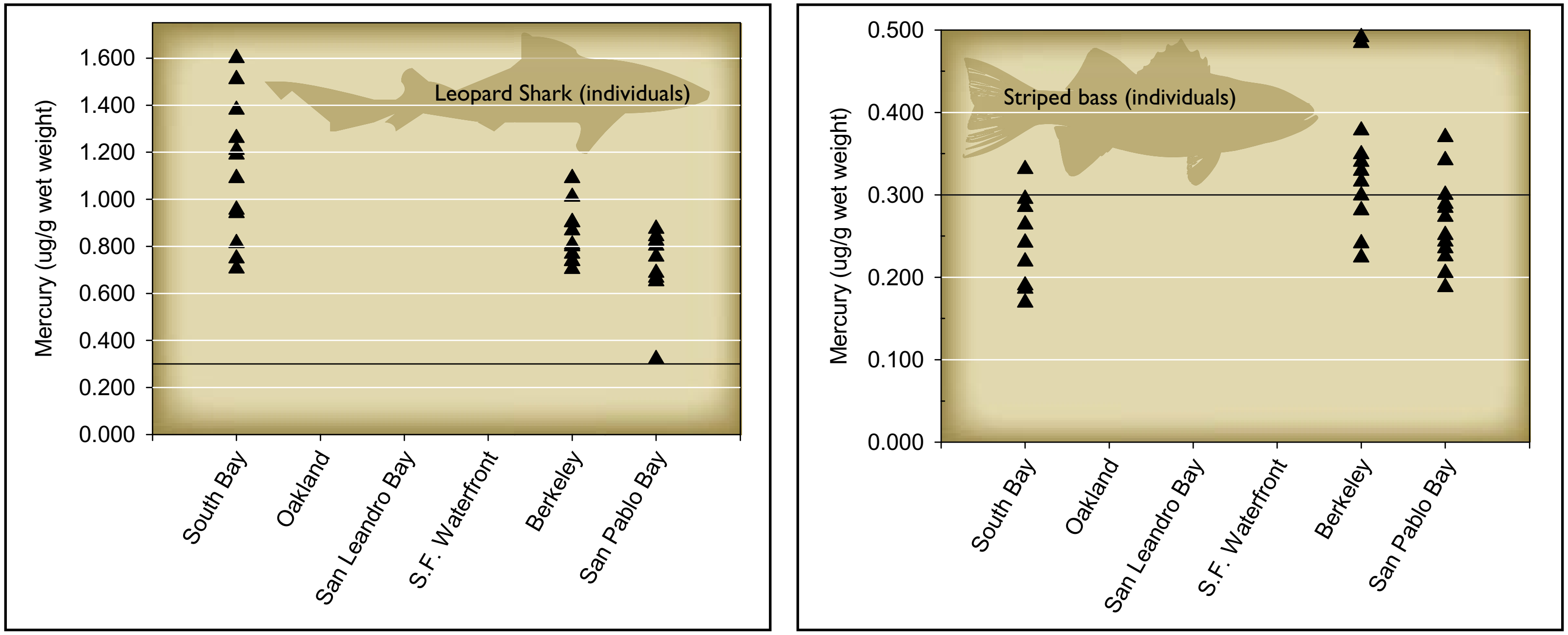


Figure 2. Mercury in Bay sport fish exceeds the threshold for human health concern, with relatively high concentrations in the South Bay. Leopard shark are the species with the highest concentrations in the Bay, and in 2000 South Bay leopard shark had significantly higher mercury than the other locations sampled. White sturgeon in South Bay were also significantly higher than in San Pablo Bay (data not shown). Concentrations in striped bass were lower in South Bay, but the difference was not statistically significant. Data from Greenfield et al. (2003).

The SBSP Restoration Project is considered in this article as a prime example of the connections of wetland restoration with Bay water quality. Contaminants have the potential to hinder the success of the Project through four principal mechanisms:

1. increases in wetland habitat may **increase mercury accumulation** in the food web;
2. **legacy sediment contamination** may impact specific restoration sites;
3. restoration may cause a regional increase in South Bay contamination through **accelerating erosion** of buried Bay sediment; and
4. **new inputs** could degrade restored habitat.

These mechanisms are each described below.

The Potential for Increased Mercury Accumulation in the Bay Food Web

Mercury accumulation in the Bay food web is already a significant problem, with concentrations that are high enough to warrant concern for the health of humans and wildlife. There is a strong possibility that restoration of thousands of acres of tidal marshes will make this problem even worse. It is even quite possible that the restored marshes in the South Bay could have as much influence on mercury accumulation in the South Bay food web as any of the other known mercury sources.

Mercury concentrations in Bay sport fish are high enough to pose risks to human health (**Figure 2**) and are a primary reason for the existence of a consumption advisory. The advisory applies to the Bay as a whole, including the South Bay where sport fish are relatively high in mercury. High mercury concentrations in the South Bay are largely attributable to the presence of the historic New Almaden mining district—historically the nation's most productive mercury mines—in the Guadalupe River watershed.

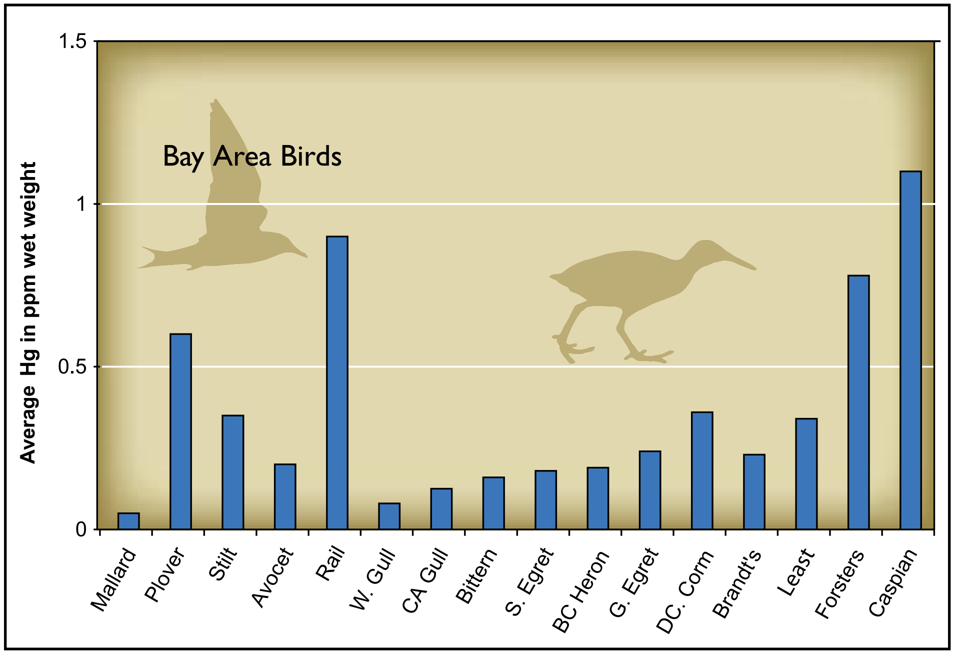


Figure 3. Mercury concentrations in the Bay food web may be high enough to impair reproduction in the endangered California clapper rail and other bird species. A study in 2000 and 2001 by the U.S. Fish and Wildlife Service (USFWS) examined mercury concentrations in eggs of many species of birds from the Estuary. Studies indicate mercury starts to become toxic to bird embryos at egg concentrations between 0.5 to 0.8 ppm. Eggs of clapper rails, Forster's terns, and Caspian terns exceeded these concentrations. Laboratory studies have shown that clapper rail embryos are relatively sensitive to mercury, leading USFWS to conclude that the concentrations measured in the rail eggs were likely toxic. Rates of reproduction in San Francisco Bay rails are lower than in other locations, and it is plausible that mercury toxicity to rail embryos is a significant contributing factor. Data from Schwarzbach and Adelsbach (2003).

Present mercury concentrations also pose significant risks to wildlife health in the South Bay. In wildlife species high mercury exposure can cause damage to nervous, excretory, and reproductive systems, and early life stages are most sensitive. One of the key species that the SBSP Project is intended to benefit is the endangered California clapper rail. This species is particularly sensitive to mercury and rail eggs in the region already have been found to contain enough mercury to cause embryo mortality (**Figure 3**). Rates of reproduction in San Francisco Bay rails are lower than in rails in other parts of the country, and it is plausible that mercury toxicity to rail embryos is a significant contributing factor (Schwarzbach et al., submitted). Schwarzbach et al. (submitted) stated that a successful recovery strategy for San Francisco Bay rails will depend on achieving appropriately protective sediment and water quality objectives for mercury within rail habitat. Clapper rail populations have withstood mercury exposures in the past that were higher than those at present and the rail populations persisted, so mercury appears to be a factor that would limit the increase of rail populations rather than one that would completely inhibit their recovery.

Wetlands, especially newly created wetlands, can generally be expected to be sites of increased production of methylmercury

Risks also exist at present levels of mercury exposure for other wildlife species that forage in the South Bay and its marshes and salt ponds. In recent sampling, Caspian tern and Forster's tern eggs had mean concentrations above a general toxic threshold for bird eggs (**Figure 3**), with many high concentrations observed in eggs from the South Bay salt ponds. Avocets, plovers, and stilts had variable concentrations with some high eggs at salt pond sites in the South Bay that exceeded the threshold concentrations. There are not yet data available to provide precise toxicological interpretation of concentrations in the stilts, plovers, and terns, but concentrations over 1 ppm in piscivorous (fish-eating) birds and over 0.5 ppm in nonpiscivorous species should probably be considered elevated (Schwarzbach and Adelsbach 2003). Other piscivorous wildlife species, such as harbor seals, are also highly exposed to mercury, though little is known about the potential impacts of this exposure. Elevated mercury concentrations have been found in blood from harbor seals inhabiting San Francisco Bay (Kopec and Harvey 1995).

Mercury exists in the environment in a variety of chemical forms. In terms of impact to humans and wildlife, the most important form of mercury in the aquatic environment is methylmercury, which is readily accumulated by biota and transferred through the food web. Methylmercury is also the most toxic form. It is well-established through many studies that wetlands, especially newly created wetlands, can generally be expected to be sites of enhanced net production of methylmercury (see page 21). Sulfur-reducing bacteria

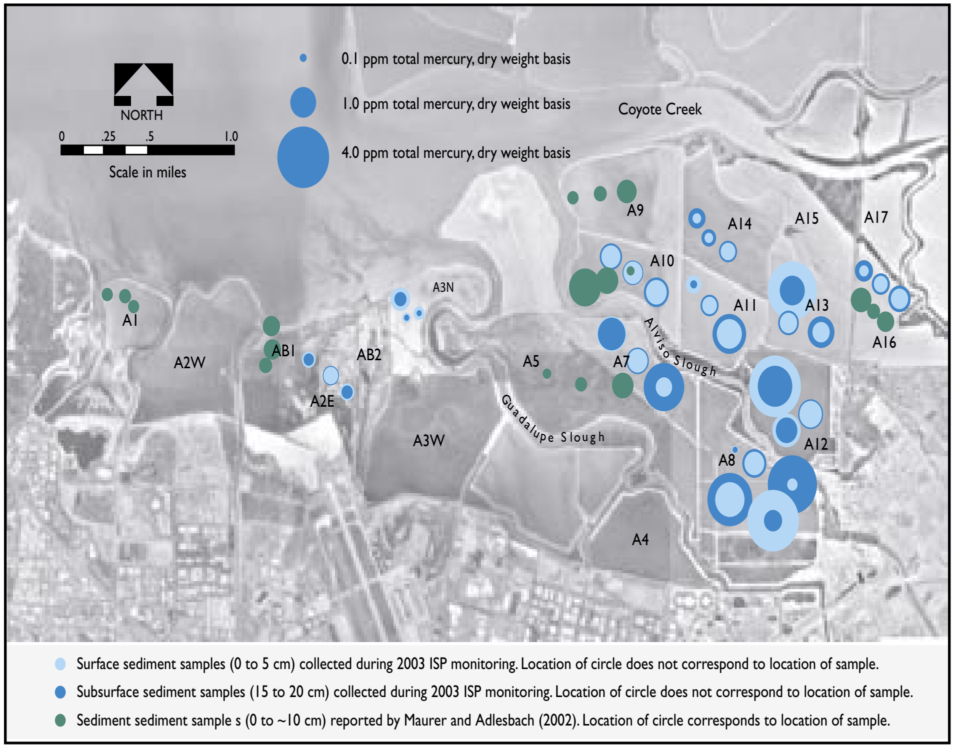


Figure 4. Legacy contamination of mercury in salt pond sediments. Mercury concentrations in some of the salt ponds are extremely high, often ten times higher than typical concentrations in the Bay (0.2 – 0.3 ppm, see page 17). Concentrations are particularly high in ponds downstream of the historic New Almaden mercury mining district. From Beutel and Abu-Saba (2004).

are abundant in wetlands due to the anaerobic conditions that prevail in these environments, and these bacteria are the main methylators of mercury. Newly created wetlands typically have an even greater supply of organic material and exhibit even more methylation. Increased methylmercury production in the restored marshes can be expected to result in greater food web accumulation both in the marshes themselves and more widely in the open waters of South Bay due to the export of methylmercury from the marshes. Several studies have found that watersheds with higher percentages of wetland habitat have higher rates of methylmercury export. In a national study of mercury contamination by USGS, wetland density was the single most important watershed-scale factor associated with methylmercury production.

Increased methylmercury in the South Bay food web would increase the health risks associated with sport fish consumption and prolong the existence of a fish consumption advisory for the region, limiting public access to the Bay fishery. Wildlife would also become more highly exposed. The greatest concerns for wildlife health would be related to possible effects on clapper rails and terns foraging at marshes with high rates of methylmercury production. Increased exposure of harbor seals and other species that forage in the open waters of South Bay would also be a concern.

The Potential Impacts of Legacy Sediment Contamination

Legacy sediment contamination at restoration sites could have a significant negative impact on the success of specific projects. Legacy sediment contamination is known to exist in the Bay, its marshes, and its watershed. Legacy contaminants that have been found at high concentrations in the sediment and food webs of marshes and salt ponds around the Bay include mercury, PCBs, and DDT. Considering mercury as an example, layers or patches of elevated mercury concentrations in sediment are distributed widely in the Bay due to past activities, especially mercury mining and hydraulic gold mining in the Sierra Nevada. Legacy mercury contamination in the South Bay is probably most influenced by historic mercury mining in the local Bay Area watersheds.

Mercury contamination of the South Bay salt ponds has been investigated in recent studies (Beutel and Abu-Saba 2004). Concentrations of total mercury in pond sediments have been found to be quite variable, with many samples well above average concentrations in Bay sediments (0.3 to 0.4 ppm) and even further above the TMDL sediment target of 0.2 ppm (**Figure 4**). Runoff from the New Almaden mercury mining district probably had a particularly large influence on sediment quality in the salt ponds and the South Bay region historically, and runoff from this watershed continues to be a principal source of mercury to the South Bay today. The distribution of legacy mercury in the salt ponds is probably related, among other factors, to the timing of salt pond establishment, which is known to have occurred over the course of nearly a century (**Figure 5**).

Urban runoff and industrial activities have also contributed to the presence of hotspots of mercury and other pollutants around the margin of the Bay. The Bay Protection and Toxic Cleanup Program, the RMP, and other studies have documented the presence of such hotspots in wetlands and other Bay margin habitats.

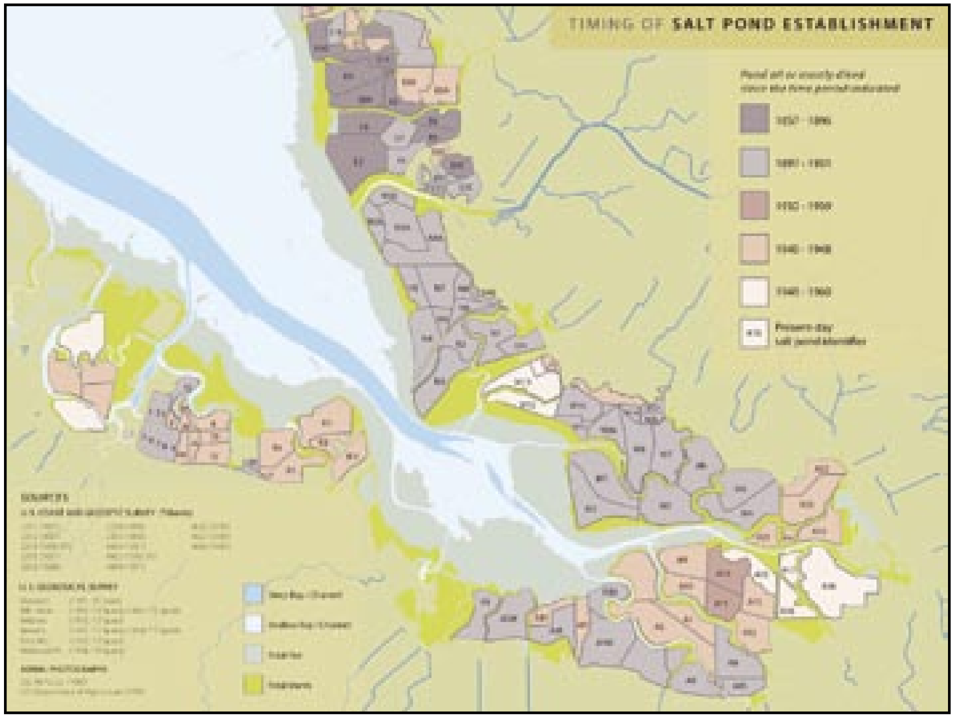


Figure 5. The timing of salt pond establishment is known and is probably a significant factor affecting legacy contamination of pond sediment. The present-day salt pond landscape was created in phases over the past 150 years. While some marshlands persisted into the second half of the 20th century, other areas have been diked nearly 150 years. Of particular interest to understanding historical mercury deposition is the location of Guadalupe and Alviso Sloughs, the two historical outlets of Guadalupe River. From Collins and Grossinger (2004).

In general, little information is available on contaminant concentrations in Bay marshes and salt ponds, but the existing data suggest that marshes and salt ponds downstream of current or historical discharges of contaminated runoff or effluent are potentially sites of legacy contamination. Prior to initiating restoration projects it would be important to screen the project site for potential legacy contamination, including mercury and other contaminants.

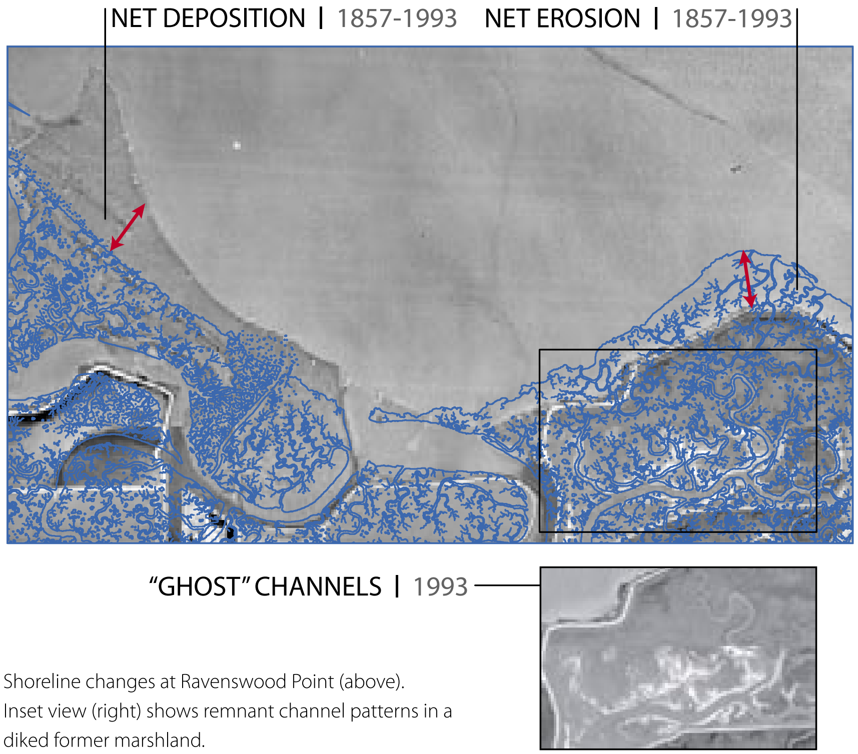
The Potential Impacts of Accelerated Erosion

Restoring tidal action to South Bay salt ponds may lead to increased erosion of contaminated sediment in the South Bay region, with potential regional impacts on water quality in both open Bay waters and in the restored marshes themselves. Studies by USGS have shown that the South Bay and other parts of the Bay have been undergoing net erosion in recent decades, largely due to a reduced supply of sediment coming in from the Central Valley. Bathymetric surveys conducted in 1931, 1956, and 1983 are the basis for the recent analysis of South Bay erosion and deposition by Foxgrover et al. (2004). From 1931 to 1956 (a period with rapid urbanization, industrialization, and little wastewater treatment), the South Bay had widespread deposition of relatively contaminated sediment. From 1956 to 1983 (a period including an era of peak contamination in the 1960s and marked improvements with the onset of wastewater treatment in the 1960s and 1970s), the South Bay experienced net erosion. The erosion and deposition varied by location, with erosion dominating in the northern part of South Bay and deposition dominating in southern South Bay. These long-term patterns of erosion and deposition are a critical piece of information needed to predict the rate of improvement of Bay water quality in decades to come. A new bathymetric survey of the South Bay is being conducted as part of the SBSP Restoration Project and will provide the information needed to evaluate the latest trends in erosion.

Opening salt ponds up to tidal action will increase the volume of water entering and exiting the South Bay on each tidal cycle, increasing current velocities and erosion. In addition, the Estuary is currently experiencing a sediment deficit. The restored salt ponds will constitute a major new sink for sediment particles that draws sediment out of the Bay (for more on this topic see article on page 58).

The potential for increased erosion poses a significant problem with respect to recovery of the South Bay from mercury and PCB contamination because the layers of sediment that are being uncovered were originally laid down in earlier decades when the Bay was generally more contaminated. Buried Bay sediment contains relatively high concentrations of mercury, PCBs, DDTs, polycyclic aromatic hydrocarbons (PAHs), and other contaminants that were deposited in the 1950s and 1960s prior to modern controls on pollution. Erosion of this contaminated sediment could delay recovery of the South Bay from impairment due to mercury, PCBs, and other persistent pollutants.

Like bottom sediments in the Bay, tidal marshes can also store large amounts of contaminants. Tidal marshes can also act as sources of contaminants, as



Shoreline changes at Ravenswood Point (above). Inset view (right) shows remnant channel patterns in a diked former marshland.

Figure 6. Tidal marshes can also act as sources of contaminants, as contaminated marsh sediment erodes. This figure overlays marshland hydrography circa 1857 on modern marsh and diked baylands at Ravenswood Point. The distribution of contaminants in now-diked marshlands is expected to be related to the pattern of historical tidal channels, which controlled the deposition of Bay sediment. Shoreline change investigation can help gauge patterns of contaminant exposure and release in the Estuary's marshes.

contaminated marsh sediment erodes (**Figure 6**). An increase in the sediment deficit of the Bay may also accelerate erosion and contaminant remobilization from these marsh sediments.

Potential Impacts of New Inputs of Pollutants

New inputs of contaminants will pose a continuing concern for restored marshes, as they will for the South Bay as a whole. New inputs could enter restored habitat from either adjoining watersheds or the atmosphere. Among the concerns are legacy contaminants such as mercury (which could be introduced via runoff or atmospheric deposition), chemicals in current use such as pyrethroid insecticides (carried by runoff) or polybrominated diphenyl ethers (PBDEs, potentially carried by runoff, wastewater treatment plant effluent, or atmospheric deposition), and contaminants such as PAHs that are still being emitted from combustion sources.

PBDEs (see page 32) are an example of an emerging contaminant that is persistent and biomagnifies, and could affect higher trophic level species in restored habitats. PBDE concentrations appear to be rising rapidly in the Bay, raising concern that another legacy contamination problem is developing. Studies of PBDE concentrations in seals, birds, and human blood, fat, and breast milk from the Bay Area have found some of the highest concentrations measured in the world. In fact, the highest PBDE concentrations measured to date *in any living thing in the world* were found in the eggs of Forster's terns nesting near salt ponds along the Hayward shoreline (She et al. 2004). In the near term, PBDE concentrations are expected to continue to rise and pose a potential health threat to terns and other higher trophic level species in the Project area. Food web monitoring is the best way to track trends in persistent, bioaccumulative contaminants such as PBDEs, mercury, PCBs, legacy pesticides, and dioxins.

Pyrethroids represent another type of emerging contaminant that could affect restored habitats by causing toxicity in fish or aquatic invertebrates and diminishing food resources for special status species and other species at higher trophic levels. Pyrethroid use has been increasing in recent years (see page 24). Fish and aquatic arthropods are quite sensitive to pyrethroids, raising concern for possible non-target impacts on aquatic environments. Toxicity testing, community assessments, and event-related chemical measurement are the best ways to assess impacts of relatively non-persistent, water soluble contaminants such as pyrethroids.

Other contaminants, such as PAHs, have been a concern for many years but continue to be released into the environment and washed downstream into the Bay and its marshes. New atmospheric inputs of contaminants, including mercury, into restored habitats are another concern.

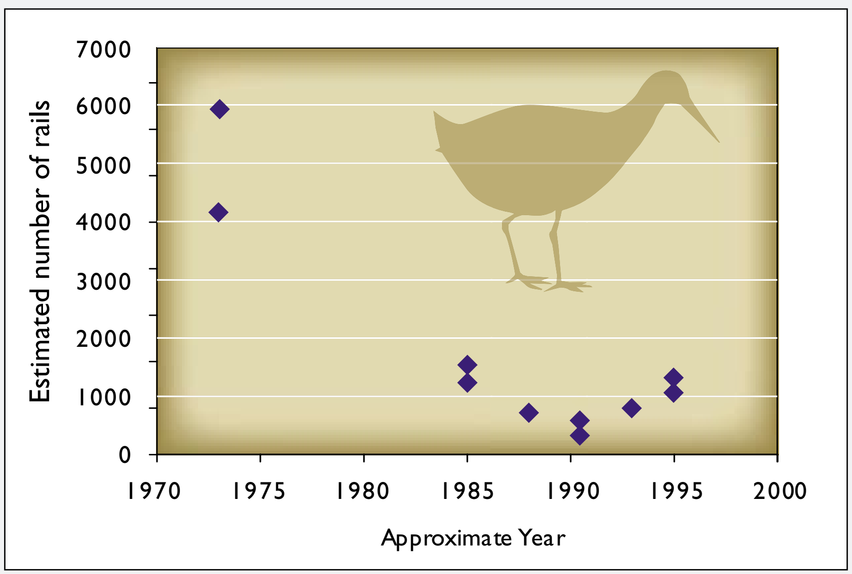
Clearly, mercury is not the only contaminant of potential concern in South Bay tidal marshes. Studies by the RMP and other programs are improving our understanding of contaminant inputs to the South Bay from local watersheds and atmospheric deposition. Coordination of the Project with the RMP will be beneficial in evaluating the potential impacts of new inputs and other water quality threats on Project objectives.

The Prudent Course of Action

A thoughtful and concerted effort will be needed to understand how restoration activities will affect water quality in the South Bay. The most prudent course of action will be to take an adaptive management approach, minimizing risk as much as possible by taking actions based on existing knowledge while conducting the research needed to reduce the negative impacts of future restoration projects and the monitoring needed to assess regional and local impacts. The following recommendations for addressing uncertainties relating to the impacts of the SBSP on water quality are distilled from Davis et al. (2003), the CBDA Mercury Strategy (Wiener et al. 2003), and the SBSP Mercury Memo (Beutel and Abu-Saba 2004).

General Recommendations

A serious, multifaceted monitoring and research effort on mercury should be an on-going part of tidal wetland restoration in the South Bay and the rest of the Estuary. The SBSP Project should be a major participant in this effort. Mercury



The years indicated are midpoints for studies that spanned more than one year. Two data points from the same time period indicate upper and lower bounds of a population size estimate, while single point denote estimates with no upper and lower bounds provided.

Data sources:

Albertson, J., & J. Evens. 2000. California Clapper Rail: species narrative. Pp 332-341 in Goals Project. Baylands Ecosystem Species and Community Profiles. Prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. P.R. Olofson, ed. San Francisco Regional Water Quality Control Board, Oakland.

Avocet Research Associates. 2004. California Clapper Rail (*Rallus longirostris obsoletus*) breeding season survey San Pablo Bay and tributaries. Final Report to Marin Audubon Society. May 28, 2004. Revised June 9, 2004.

Collins, J., J.G. Evens, and B. Grewell. 1994. A synoptic survey of the distribution and abundance of the California clapper rail, *Rallus longirostris obsoletus*, in the northern reaches of the San Francisco Estuary during the 1992 and 1993 breeding seasons. Technical Report to California Department of Fish and Game.

Trends in the California Clapper Rail Population

Promoting the recovery of the California Clapper Rail (*Rallus longirostris obsoletus*) is one of the primary aims of the SBSP Restoration Project. Clapper Rails have experienced a severe decline in numbers over the past 150 years. The entire world population of this endangered species now resides in the San Francisco Estuary, since breeding populations in outer marshes have been extirpated over the past 30 years. The majority of rails are found in the South Bay, with a significant proportion of the population in San Pablo Bay, and very few in the Suisun marshes. The California Clapper Rail was listed as Federally Endangered in 1970 and State Endangered in 1971. This figure was compiled from a variety of different research efforts, rather than a coherent, region-wide monitoring program. The 1970s study may have overestimated the population size, and the more recent numbers reflect minimum population estimates. Despite these caveats, the rails clearly declined precipitously in the 1980s, likely due in part to predation by the introduced red fox (*Vulpes fulva*). Predator control and active management have probably aided the rebound in populations in the 1990s, in the South Bay especially. A 2004 study of San Pablo Bay and tributaries indicated a decrease in the number and distribution of rails. Comprehensive surveys by Avocet Research Associates and the Point Reyes Bird Observatory over the next two years will provide an update on overall population trends. Present concentrations of mercury in Bay marshes are thought to be high enough to cause mortality in some Clapper Rail embryos, and tidal marsh restoration may result in even higher concentrations in the food web.

is the contaminant that poses the greatest threat to the success of the SBSP Project and that is likely to be most affected by the Project. The complexity of the mercury cycle and the rudimentary state of current understanding limit our present ability to predict which specific restoration projects will lead to unacceptable mercury bioaccumulation. These are challenging problems and it will take some time to find the necessary, creative solutions.

Effective coordination of SBSP studies with studies by other programs will be crucial to successfully and cost-effectively addressing contaminant concerns. Major investments are being made by the CBDA (see article on page 64), the RMP, and others to improve understanding of mercury and other contaminants in the Bay-Delta. The SBSP has much to gain by being informed of findings from these other efforts and building on them, rather than duplicating them. Participation of the SBSP Project in the RMP would be an effective way to integrate the two programs and for the SBSP to leverage existing RMP efforts to evaluate contaminant sources and loadings, trends, fate, and effects in the South Bay.

Specific Recommendations

Long-term food web monitoring should be performed to ascertain the impact of restoration actions on water quality on both a regional and local scale. This monitoring should include sampling sport fish, forage fish, avian eggs, and lower trophic level bioindicator organisms. Long-term monitoring of individual restoration projects should be conducted in coordination with regional monitoring and assessment.

Long-term monitoring of other water quality indicators will also be needed to detect impacts of mercury and other contaminants on the Project. The SBSP Project will need information on contaminant loads to the South Bay, the general health of key species and communities, toxicity of water and sediment, and general trends in contaminant concentrations in the South Bay ecosystem. The RMP provides a mechanism for addressing all of these issues in an integrated manner, and coordinating with other related projects.

Detailed surveys should precede restoration projects to document existing concentrations of mercury and other contaminants in affected areas and to evaluate the potential for increased food web accumulation. The presence and potential presence of contaminants in the water and sediment supply of restored wetlands should also be evaluated in the planning stages of each restoration project.

Process studies should be performed in a strategic way so that mechanisms of variation in mercury accumulation among tidal wetlands can be understood. This will provide the foundation needed by environmental managers and engineers to develop designs that minimize the impact of restoration activities. High priority should be given to examining effects of restoration on methylmercury production and entry into the food web.

Alternative restoration project designs should be evaluated for their potential to minimize methylmercury accumulation in the food web. The most promising alternatives should be implemented in an adaptive management context coupled with careful monitoring and, where appropriate, process studies.

An understanding of the role of tidal wetlands as net methylmercury importers from or exporters to the Estuary is needed. Evaluations should include measurements of methylmercury export and methylation and demethylation in water and sediment of different tidal wetland environments.

Transfer of mercury and other contaminants through the food web to species at risk, including humans, must be understood. This should include an understanding of the factors controlling mercury accumulation in species involved in restoration, such as clapper rails. The link between food web contamination and human exposure also should be documented through study of fishing and fish consumption practices.

Better information is needed on the sensitivity of species facing the greatest exposure to methylmercury and other contaminants. Available information indicates that California clapper rails are highly exposed to methylmercury and highly sensitive – these observations should be further defined and confirmed. Study of the possible impacts of mercury on seals is warranted. Piscivorous wildlife are also highly exposed to PCBs, dioxins, PBDEs, and other persistent organic chemicals, and the sensitivity of these species to these chemicals individually and in combination is not well known.

Conceptual and numerical models of contaminant fate are needed on both regional and local scales. Conceptual models provide a valuable framework for organizing and describing the current state of knowledge and defining uncertainties, and should continue to be updated with new information. Numerical models are needed to predict the regional impacts of the Project on accelerating erosion of sediment deposits. When the process studies have reached a stage of development that allows reliable predictions to be made, numerical models can also be applied in this context.

To allow for effective adaptive management decisions as the Project is implemented, the major uncertainties need to be further evaluated and prioritized. This prioritization should be done through an open, group process involving scientists and managers.

References

Status and Trends Update

Fairey, R., K. Taberski, S. Lamerdin, E. Johnson, R. P. Clark, J. W. Downing, J. Newman and M. Petreas. 1997. Organochlorines and other environmental contaminants in muscle tissues of sportfish collected from San Francisco Bay. Marine Pollution Bulletin 34(12): 1058-1071.

White, J.R., Hofmann, P.S., Urquhart, K.A.F., Hammond, D. and S. Baumgartner. 1989. Selenium Verification Study 1987-1988: A report to the State Water Resources Control Board. California Department of Fish and Game.

Cohen, A. N. and J. T. Carlton. 1998. Accelerating invasion rate in a highly invaded estuary. Science 279: 555-558.

Caltrans 2002. California motor vehicle stock, travel and fuel forecast. California Department of Transportation, Division of Transportation System Information in cooperation with the U.S. Department of Transportation, Federal Highway Administration, November 2002. pp63.

Important Findings From Other Studies

Alpers, C.N., Hunerlach, M.P., Marvin-DiPasquale, M., Snyder, N.P., and Krabbenhoft, D.P., 2004a, Mercury and methylmercury in the upper Yuba River watershed: Fluvial transport and reservoir sedimentation. Third Biennial CALFED Bay-Delta Program Science Conference Abstracts, October 4-6, 2004, Sacramento, Calif., p. 4.

Alpers, C.N., Marvin-DiPasquale, M., Agee, J., Slotton, D.G., Ayers, S., Saiki, M.K., Martin, B.A., May, T.W., Hunerlach, M.P., and Humphreys, R.D., 2004b, Mercury contamination, methylation, and bioaccumulation in an area affected by large-scale gold dredging: Lake Natoma drainage, American River watershed, California. 14th Annual Meeting, Northern California Regional Chapter, Society of Environmental Toxicology and Chemistry (NorCal SETAC), May 11-12, 2004, Davis, CA.

Alpers, C.N., Marvin-DiPasquale, M.P, Kuwabara, J.S., Stewart, A.R., Saiki, M., Krabbenhoft, D.P., Taylor, H.E., Kester, C.L., Rye, R.O., 2003, Studies of mercury transport, transformation, and bioaccumulation in the Bear River, California: A watershed affected by historical gold mining, American Society of Limnology and Oceanography, Aquatic Sciences Meeting, Salt Lake City, UT, Feb. 2003

Collins, J.N., C. Grosso, and E. Wittner. 2005. San Francisco Bay Area Intensification Project for the Western Environmental Monitoring and Assessment Program (WEMAP) of 2002. Wetlands Science Program, San Francisco Estuary Institute, Oakland CA.

Kieu, L.H., 2004, The seasonal influence of saltmarsh plants (Salicornia virginica and Scirpus robustus) on methylmercury production and degradation over small spatial scales in South San Francisco Bay: San Francisco, San Francisco State University, Master's Thesis, 72 p.

Marvin-DiPasquale, M., Agee, J., Bouse, R., and Jaffe, B., 2003, Microbial cycling of mercury in contaminated pelagic and wetland sediments of San Pablo Bay, California: Environmental Geology, v. 43, no. 3, p. 260-267.

Marvin-DiPasquale, M., 2004, Mercury cycling concepts important in adaptive management of wetland restoration. Third Biennial CALFED Bay-Delta Program Science Conference Abstracts, October 4-6, 2004, Sacramento, Calif.

Solomon KR, Giddings JM, Maund SJ. 2001. Probabilistic risk assessment of cotton pyrethroids: I. Distributional analyses of laboratory aquatic toxicity data. Environ Toxicol Chem 20:652-659.

Polybrominated Diphenyl Ether (PBDE) Flame Retardants in San Francisco Bay

Alaee, M., Luross, J., Sergeant, D.B., Muir, D.C.G., Whittle, D.M., Solomon, K. 1999. Distribution of polybrominated diphenyl ethers in the Canadian environment. Organohalogen Compounds 40:347-350.

BSEF. 2003. Bromine Science and Environmental Forum. *Total Market Demand*. www.bsef.com.

CRWQCB. 2004. PCBs in San Francisco Bay Total Maximum Daily Load Project Report. California Regional Water Quality Control Board, San Francisco Bay Region, Oakland, CA.

Darnerud, P.O., Eriksen, G.S., Johannesson, T., Larsen, P.B., Viluksela, M. 2001. Polybrominated diphenyl ethers: occurrence, dietary exposure, and toxicology. Environmental Health Perspectives 109:49-68.

Geyer, H.J., Schramm, K.W., Darnerud, P.O., Aune, M., Feicht, E.A., Fried, K., Henkelmann, B., Lenoir, D., Schmid, P., McDonald, T.A. 2004. Terminal elimination half-lives ($T_{1/2H}$) of the brominated flame retardants TBBPA, HBCD, and lower brominated PBDEs in humans. Organohalogen Compounds 66:3867-3871.

Hites, R.A. 2004. Polybrominated diphenyl ethers in the environment and in people: a meta-analysis of concentrations. Environmental Science and Technology 38:945-956.

Holden, A., She, J., Tanner, M., Lunder, S., Sharp, R., Hooper, K. 2003. PBDEs in the San Francisco Bay Area: measurement in fish. Organohalogen Compounds 61:255-258.

Ikonomou, M.G., Rayne, S., Fischer, M., Fernandez, M.P., Cretney, W. 2002. Occurrence and congener profiles of polybrominated diphenyl ethers (PBDEs) in environmental samples from coastal British Columbia, Canada. Chemosphere 46:649-663.

Lichtensteiger, W., Ceccatelli, R., Faass, O., Ma, R., Schlumpf, M. 2003. Effect of polybrominated diphenylether and PCB on the development of the brain-gonadal axis and gene expression in rats. Organohalogen Compounds 61:84-87.

McDonald, T.A. 2002. A perspective on the potential health risks of PBDEs. Chemosphere 46:745-775.

McDonald, T.A. 2004. Distribution of PBDE levels among U.S. women: estimates of daily intake and risk of developmental effects. Proceedings of the Third International Workshop on Brominated Flame Retardants. BFR2004, Toronto, p 443-446.

McDonald, T.A., 2005. PBDE levels among U.S. women: daily intake and risk of harm to the developing brain and reproductive organs. Integrated Environmental Assessment and Management (submitted).

Meerts, I.A., Letcher, R.J., Hoving, S., Marsh, G., Bergman, A., Lemmen, J.G., van Der Burg, B., Brouwer, A. 2001. In vitro estrogenicity of polybrominated diphenyl ethers, hydroxylated PBDEs, and polybrominated bisphenol A compounds. Environmental Health Perspectives 109:399-407.

Meironyté, G.D., Norén, K., Bergman, A. 1999. Analysis of polybrominated diphenyl ethers in Swedish human milk. A time-related trend study, 1972-1997. Journal of Toxicology and Environmental Health, Part A. 58:101-113.

North, Karin. 2004. Tracking polybrominated diphenyl ether releases in a wastewater treatment plant effluent, Palo Alto, California. Environmental Science and Technology, 38:4484-4488.

Norstrom, R.J., Simon, M., Moisey, J., Wakeford, B., Chip Weseloh, D.V. 2002. Geographical distribution (2000) and temporal trends (1981-2000) of brominated diphenyl ethers in Great Lakes herring gull eggs. Environmental Science and Technology 36:4783-4789.

Oros, D.R., David, N. 2002. Identification and evaluation of unidentified organic contaminants in the San Francisco Estuary. San Francisco Estuary Regional Monitoring Program for Trace Substances (RMP) Technical Report: SFEI Contribution 45. San Francisco Estuary Institute, Oakland, CA.

Oros, D.R., Hoover, D., Rodigari, F., Crane, D., Sericano, J. 2005. Levels and distribution of polybrominated diphenyl ethers in water, surface sediments, and bivalves from the San Francisco Estuary. Environmental Science and Technology 39:33-41.

Petreas, M., She, J., Brown, F.R., Winkler, J., Windham, G., Rogers, E., Zhao, G., Bhatia, R., Charles, M.J. 2003. High body burdens of 2,2',4,4'-tetrabromodiphenyl ether (BDE-47) in California women. Environmental Health Perspectives 111:1175-1179.

Rice, D.A. 2000. Specific examples of impacts of toxicants on the developing and maturing nervous system. Children's Health Environmental Symposium, OEHHA, California EPA, Sacramento, May 1, located at www.oehha.ca.gov/public_info/public/kids/pdf/rice.pdf.

Sellström, U., Jansson, B., Kierkegaard, A., de Wit, C., Odsjö, T., Olsson, M. 1993. Polybrominated diphenyl ethers (PBDE) in biological samples from the Swedish Environment. Chemosphere 26:1703-1718.

SFEI. 2004. 2002 Annual Monitoring Results. San Francisco Estuary Regional Monitoring Program for Trace Substances (RMP), San Francisco Estuary Institute, Oakland, CA, 2004.

She, J., Petreas, M., Winkler, J., Visita, P., McKinney, M., Kopec, D. 2002. PBDEs in the San Francisco Bay Area: measurements in harbor seal blubber and human breast adipose tissue. Chemosphere 46:697-707.

She, J., Holden, A., Tanner, M., Sharp, M., Adelsbach, T., Hooper, K. 2004. Highest PBDE levels (max 63 ppm) yet found in biota measured in seabird eggs from San Francisco Bay. Organohalogen Compounds 66:3939-3944.

Söderström, G., Sellström, U., de Wit, C.A., Tysklind, M. 2004. Photolytic debromination of decabromodiphenyl ether (BDE 209). Environmental Science and Technology 38:127-132.

Stapleton, H.M., Alaee, M., Letcher, R.J., Baker, J.E. 2004. Debromination of the flame retardant decabromodiphenyl ether by juvenile carp (*Cyprinus carpio*) following dietary exposure. Environmental Science and Technology 38:112-119.

Thomsen, C., Lundanes, E., Becher, G. 2002. Brominated flame retardants in archived serum samples from Norway: A study on temporal trends and the role of age. Environmental Science and Technology 36:1414-1418.

von Meyerinck, L., Hufnagel, B., Schmoldt, A., Benthe, H.F. 1990. Induction of rat liver microsomal cytochrome P-450 by the pentabromo diphenyl ether Bromkal 70 and half-lives of its components in the adipose tissue. Toxicology 61:259-274.

Wilford, B.H., Harner, T., Zhu, J., Shoeib, M., Jones, K.C. 2004. Passive sampling survey of polybrominated diphenyl ether flame retardants in indoor and outdoor air in Ottawa, Canada: implications for sources and exposure. Environmental Science and Technology 38:5312-5318.

The Legacy of Organochlorine Pesticides in San Francisco Bay

Carson, R. 1962. *Silent Spring*. Cambridge, MA: The Riverside Press. 368 p.

Connor, M., J. Davis, J. Leatherbarrow, and C. Werme. 2004. Legacy pesticides in San Francisco Bay: Conceptual model/impairment assessment. Prepared for Clean Estuary Partnership. 84 p.

Davis, J.A., M.D. May, S.E. Wainwright, R. Fairey, C. Roberts, G. Ichikawa, R. Tjeerdema, M. Stoelting, J. Becker, M. Petreas, M. Mok, M. McKinney, and K. Taberski. 1999. Contaminant concentrations in fish from San Francisco Bay, 1997. San Francisco Estuary Institute, Richmond, CA.

Davis, J.A., K. Abu Saba, and A.J. Gunther. 2001. Technical Report of the Sources, Pathways, and Loadings Workgroup. San Francisco Estuary Institute, Richmond, CA.

Fairey R, Taberski K, Lamerdin S, Johnson E, Clark RP, Downing JW, et al. Organochlorines and other environmental contaminants in muscle tissues of sportfish collected from San Francisco Bay. Mar Pollut Bull 1997;34:1058– 71.

Foxgrover, A., S. Higgins, M. Ingraca, B. Jaffe, and R. Smith. 2003. Sedimentation and bathymetry changes in South San Francisco Bay: 1858 – 1983. United States Geological Survey. Abstracts of the 6th Biannual State of the Estuary Conference. October 21-23, 2003. Oakland, CA.

Greenfield, B.K., J.A. Davis, R. Fairey, C. Roberts, D.B. Crane, G. Ichikawa, and M. Petreas. 2003. Contaminant concentrations in fish from San Francisco Bay, 2000. RMP

Technical Report: SFEI Contribution 77. San Francisco Estuary Institute, Oakland, CA. 82p.

Gunther, A.J., J.A. Davis, D.D. Hardin, J. Gold, D. Bell, J.R. Crick, G.M. Scelfo, J. Sericanon, and M. Stephenson. 1999. Long-term bioaccumulation monitoring with transplanted bivalves in the San Francisco Estuary. *Marine Pollution Bulletin* 38: 170-181.

Johnson, B. and R. Looker. 2003. Mercury in San Francisco Bay: Total maximum daily load (TMDL) report. Prepared for the California Regional Water Quality Control Board, San Francisco Bay Region. 87 p.

Leatherbarrow, J.E., N. David, B.K. Greenfield, and J.A. Davis. 2003. Organochlorine pesticide fate in San Francisco Bay. RMP Technical Report. San Francisco Estuary Institute. Oakland, CA.

Leatherbarrow, J.E., L.J. McKee, D.H. Schoellhamer, N.K. Ganju, and A.R. Flegal. 2004. Concentrations and loads of mercury and hydrophobic organic contaminants associated with the suspended-sediment flux between the Sacramento-San Joaquin River Delta and San Francisco Bay. RMP Technical Report. San Francisco Estuary Institute. Oakland, CA.

McKee, L.J. and C. Foe. 2002. Estimation of total mercury fluxes entering San Francisco Bay from the Sacramento and San Joaquin River watersheds. Technical memorandum prepared for the San Francisco Bay Regional Water Quality Control Board. December 23, 2002. San Francisco Estuary Institute. Oakland, CA.

McKee, L.J., N. Ganju, D. Schoellhamer, D. Yee, J.A. Davis, J.E. Leatherbarrow, and R. Hoenicke. 2002. Estimates of suspended-sediment flux entering San Francisco Bay from the Sacramento and San Joaquin Delta. RMP Technical Report. San Francisco Estuary Regional Monitoring Program. SFEI Contribution 65. San Francisco Estuary Institute. Oakland, CA.

Thompson, B., B. Anderson, J. Hunt, K. Taberski, and B. Philips. 1999. Relationships between sediment contamination and toxicity in San Francisco Bay. *Marine Environmental Research* 48: 285-309.

Yee, D., J.E. Leatherbarrow, and J.A. Davis. 2001. South Bay/Fairfield-Suisun Trace Organic Contaminants in Effluent Study. Prepared for the San Jose/Santa Clara Water Pollution Control Plant, Sunnyvale Water Pollution Control Plant, Palo Alto Regional Water Quality Control Plant, and Fairfield-Suisun Sewer District. San Francisco Estuary Institute. Richmond, CA.

Bay Area Activities of The Surface Water Ambient Monitoring Program (SWAMP)

Brodberg, R. K. and G.A. Pollock. 1999. *Prevalence of Selected Target Chemical Contaminants in Sport Fish from Two California Lakes: Public Health Designed Screening Study.* California Environmental Protection Agency, Office of Environmental Health Hazard Assessment.

Bay Sediment Budgets: Sediment Accounting 101

Buchanan, P.A., and Ganju, N.K., 2004. Summary of suspended-sediment concentration data, San Francisco Bay, California, Water Year 2002: U.S. Geological Survey Open File Report 2004-1219. http://pubs.water.usgs.gov/ofr2004-1219/

California Department of Water Resources. 1986. DAYFLOW program documentation and DAYFLOW data summary user's guide. URL http://www.iep.ca.gov/dayflow/data/

Cappiella, K, Malzone, C, Smith, R. E., and Jaffe, B. E. 1999. Sedimentation and bathymetry changes in Suisun Bay, 1867-1990: U.S. Geological Survey Open-File Report 99-563.

Flick, R.E, J.F. Murray and L.C. Ewing. 2003. Trends in United States tidal datum statistics and tide range. J. Waterway, Port, Coastal and Ocean Eng., 129(4): 155-164.

Foxgrover, A.C, Higgins, S.A., Ingraca, M.K., Jaffe, B.E. and Smith, R.E., 2004, Deposition, erosion and bathymetric change in South San Francisco Bay: 1858-1983, U.S. Geological Survey Open-file Report 2004-1192, 25 p. http://pubs.usgs.gov/of/2004/1192/of2004-1192.pdf

Hanson, C.H., Coil, J., Keller, B., Johnson, J., Taplin, J., and Monroe, J., 2004, Assessment & Evaluation Of The Effects Of Sand Mining On Aquatic Habitat And Fishery Populations Of Central San Francisco Bay And The Sacramento–San Joaquin Estuary: Hanson Environmental Inc., Walnut Creek, California.

Jaffe, B. E., Smith, R. E., and Torresan, L. Z. 1998. Sedimentation and bathymetric change in San Pablo Bay: 1856 to 1983: U.S. Geological Survey Open-File Report 98-759.

Lionberger, M.A., 2003, A Tidally-Averaged Sediment Transport Model of San Francisco Bay, California: Masters thesis, Department of Civil and Environmental Engineering, University of California at Davis, 96 p.

McKee, L.J. and C. Foe. 2002. Estimation of total mercury fluxes entering San Francisco Bay from the Sacramento and San Joaquin River watersheds. Technical memorandum prepared for the San Francisco Bay Regional Water Quality Control Board. December 23, 2002. San Francisco Estuary Institute. Oakland, CA.

Ogden Beeman and Associates and Ray B. Krone and Associates, 1992, Sediment budget study for San Francisco Bay: Final Report prepared for the San Francisco District, U.S. Army Corps of Engineers.

Porterfield, G., 1980, Sediment transport of streams tributary to San Francisco, San Pablo, and Suisun Bays, California, 1909–1966: U.S. Geological Survey Water-Resources Investigations Report 80-64, 91 p.

Rubin, D.M., and McCulloch, D.S., 1979, The movement and equilibrium of bedforms in central San Francisco Bay: San Francisco Bay: The Urbanized Estuary, Conomos, T.J. ed., Pacific Division of the American Association for the Advancement of Science, San Francisco, pp. 97-113.

Ruhl, C.A., Schoellhamer, D.H., Stumpf, R.P., and Lindsay, C.L., 2001, Combined use of remote sensing and continuous monitoring to analyse the variability of suspended-sediment concentrations in San Francisco Bay, California: Estuarine, Coastal and Shelf Science, v. 53, p. 801-812.

Uncles, R.J., and Peterson, D.H., 1995, A computer model of long-term salinity in San Francisco Bay: sensitivity to mixing and inflows: Environmental International, v. 21, no. 5, p. 647-656.

Wright, S.A., and Schoellhamer, D.H., 2004, Trends in the Sediment Yield of the Sacramento River, California, 1957 – 2001: San Francisco Estuary and Watershed Science. v. 2, no. 2, article 2. http://repositories.cdlib.org/jmie/sfews/vol2/iss2/art2

The CALFED Bay-Delta Program: A Major Investment in Improving Water Quality in the Estuary

Brown, C.L.; Luoma, S.N. Use of the euryhaline bivalve (Potamocorbula amurensis) as a biosentinel species to assess trace metal contamination in San Francisco Bay. Mar. Ecol. Prog. Ser. 1995, 124, 129-142

Deng, D.F.; Teh, S.J.; Hung, S.O.; "Selenium Depuration: Effects on Growth and Tissue Concentrations in Juvenile Splittail": Poster

Deng, X.; Teh, S.J.; Hung, S.O.; "Toxic Effects of Dietary Selenium in Sacramento Splittail": Poster

Feyrer, F.; Herbold, B.; Matern, S.A.; Moyle, P.B Dietary shifts in a stressed fish assemblage: Consequences of a bivalve invasion in the San Francisco Estuary. Environ. Biol. Fishes 2003, 67, 277-288

Hodson, P.V.; Hilton, J.W.; The nutritional requirements and toxicity to fish of dietary and waterbourne selenium. Ecol. Bull. 1983, 335-340.

Linares, J.; Linville, R.G.; Van Eenennaam, J.; Doroshov, S.; Selenium Effects on Health and Reproduction of White Sturgeon in the Sacramento-San Joaquin Estuary. Final Report for CALFED Project ERP-02-P35. November 2004.

Linville, R.G.; Luoma, S.N.; Currter, L.; Cutter, G.A. Increased selenium threat as a result of invasion of the exotic bivalve (Potamocorbula amurensis) into the San Francisco Bay-Delta. Aquat. Toxicol. 2002, 57, 65-84

Teh, S.J.; Deng, X.; Deng, D.F.; Teh, F.; Hung, S.O.; Selenium-induced teratogenicity in Sacramento Splittail (Pogonichthys macrolepidotus); Marine Environmental Research 54 (2002) 605-608

Teh, S.J.; Deng, X.; Deng, D.F.; Teh, F.; Hung, S.O.; Fan, T.W.M.; Liu, J.; Higashi, R; Chronic Effects of Dietary Selenium on Juvenile Sacramento Splittail (Pogonichthys macrolepidotus) Environ. Sci. Technol. 2004, 38, 6085-6093.

Wiener, J.G., C.C. Gilmour, and D.P. Krabbenhoft. 2003. Mercury Strategy for the Bay-Delta Ecosystem: A Unifying Framework for Science, Adaptive Management, and Ecological Restoration. Report to the California Bay Delta Authority.

Water Quality Concerns Related To The South Bay Salt Pond Restoration Project

Beutel, M. and K. Abu-Saba. 2004. Mercury Technical Memorandum – Final Draft. South Bay Salt Pond Restoration Project. http://www.southbayrestoration.org/Documents.html#tr

Collins, J.N. and R.M. Grossinger. 2004. Synthesis of scientific knowledge concerning estuarine landscapes and related habitats of the South Bay Ecosystem. Technical Report of the South Bay Salt Pond Restoration Project. San Francisco Estuary Institute, Oakland, CA.

Davis, J.A., J.N. Collins, D. Yee, S. Schwarzbach, and S.N. Luoma. 2003. Issues in San Francisco Estuary tidal wetlands restoration: Potential for increased mercury accumulation in the Estuary food web. San Francisco Estuary and Watershed Science 1: issue 1, article 4.

Foxgrover, A.C., Higgins, S.A., Ingraca, M.K., Jaffe, B.E., and Smith, R.E., 2004, Deposition, erosion, and bathymetric change in South San Francisco Bay: 1858-1983: U.S. Geological Survey Open-File Report 2004-1192, 25 p. [URL: http://pubs.usgs.gov/of/2004/1192]

Greenfield, B. K., J.A. Davis, R. Fairey, C. Roberts, D. Crane, G. Ichikawa and M. Petreas. 2003. Contaminant concentrations in fish from San Francisco Bay, 2000. SFEI Contribution #77. San Francisco Estuary Institute, Oakland, CA.

Kopec, A.D. and J.T. Harvey. 1995. Toxic pollutants, health indices, and population dynamics of harbor seals in San Francisco Bay, 1989-1992. Moss Landing Marine Laboratories Technical Report 96-4. Moss Landing, CA. 168 pp.

Schwarzbach, S. and T. Adelsbach. 2003. CALFED Bay-Delta Mercury Project – Subtask 3B: Field Assessment of avian mercury exposure in the Bay-Delta ecosystem. http://loer.tamug.tamu.edu/calfed/FinalReports.htm

Schwarzbach, S.E., Albertson, J.D. and C. M. Thomas. Submitted. Impacts of predation, flooding and contamination on the reproductive success of the California clapper rail (Rallus longirostris obsoletus) in San Francisco Bay. The Auk.

She, J., A. Holden, M. Tanner, M. Sharp, T. Adelsbach, and K. Hooper. 2004. Highest PBDE levels (max 63 ppm) yet found in biota measured in seabird eggs from San Francisco Bay. Organohalogen Compounds 66: 3939-3944.

Wiener, J.G., C.C. Gilmour, and D.P. Krabbenhoft. 2003. Mercury Strategy for the Bay-Delta Ecosystem: A Unifying Framework for Science, Adaptive Management, and Ecological Restoration. Report to the California Bay Delta Authority.

The 303(d) List and the San Francisco Estuary

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

The SWRCB most recently compiled a 303(d) list for the State on February 4, 2003. This list was revised and approved by USEPA on July 25, 2003. Based on a review of the 2003 list, the primary pollutants/stressors for the Estuary and its major tributaries include:

Trace elements: Mercury, Nickel, and Selenium

Pesticides: Chlordane, DDT, Diazinon, and Dieldrin

Other chlorinated compounds: PCBs, Dioxin, and Furan Compounds

Others: Exotic species, Nutrients, and Pathogens

Mercury and PCBs have been ranked as a high priority for developing TMDLs. A TMDL report for mercury was adopted by the San Francisco Bay Regional Water Quality Control Board (Regioanl Board) on September 15, 2004. After reviewing the mercury TMDL, the SWRCB tabled approval of the TMDL in March 2005. The SWRCB directed the Regional Board to develop integrated TMDLs for the Sacramento/San Joaquin Delta, San Francisco Bay, and the Guadalupe River. As this Pulse goes to press, the Regional Board is in the process of developing a report that will indicate how it will address the SWRCB recommendations. With regard to a TMDL for PCBs, it is anticipated that the PCB TMDL will be proposed for adoption in Spring 2006.

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

303(d) listing for Region 2 (which includes the Estuary)

> www.waterboards.ca.gov/sanfranciscobay/303dlist.htm

TMDLs

> www.waterboards.ca.gov/sanfranciscobay/tmdlmain.htm

> www.epa.gov/owow/tdml/

Mercury TMDL

> www.waterboards.ca.gov/sanfranciscobay/sfbaymercurytmdl.htm

The 303(d) Watch List

In 2001, the Regional Board developed a 303(d) watch list of potential threats to water quality. This is a list for pollutants where anecdotal information suggests they may be causing impairment but either the available data are inadequate to draw firm conclusions or the adequacy of the regulatory program in place to control the pollutant is uncertain.

The watch list for the Estuary includes the following chemicals:

San Francisco Bay – Copper, Nickel, PAHs and PBDEs

Castro Cove, Central Basin, Oakland Inner Harbor and San Leandro Bay – Sediment Toxicity

Urban Creeks, Lakes and Shorelines – Trash

Credits and Acknowledgements

Editors: Jay Davis, Michael Connor

Contributing Authors: Jay Davis, Michael Connor, Meg Sedlak

Information Compilation: Sarah Lowe, Jennifer Hunt, Meg Sedlak, Lester McKee

GIS Mapping: Kristen Larned, Predrag Stevanovic

Report design and layout: Patricia Chambers, Andreas Schueller, Linda Wanczyk

Information graphics: Patricia Chambers, Linda Wanczyk

Cover photos courtesy of: Charles Benton (Golden Gate Bridge), Don Weden, Jon Leatherbarrow

Additional photos courtesy of: David Bell, Karin Tuxen, Andreas Schueller, Andrew N. Cohen

Symbols for diagram (in article on Adapting the RMP) courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science

Astronaut photographs courtesy of the International Space Station Crew Earth Observations Experiment and the Image Science & Analysis Group, NASA Johnson Space Center, http://eol.jsc.nasa.gov/.

Printing: Alonzo Printing, www.alonzoprinting.com

*

The efforts of those who provided comments on draft editions of the Pulse are gratefully acknowledged: Sheila Tucker, Ariel Rubissow-Okamoto, Lester McKee, Meg Sedlak, Karen Taberski, Don Yee, Kathy Dadey, Chris Sommers, Jon Konnan, Adam Olivieri, Jennifer Hunt, Michael May, John Ross.

A Primer on Bay Contamination

Q How contaminated is the Estuary?

Answer Water and sediment of the Estuary meet cleanliness guidelines for most pollutants. However, a few problem pollutants are widespread in the Estuary, making it rare to find water or sediment in the Estuary that is completely clean. A fish consumption advisory remains in effect due to concentrations of mercury, 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 58% of sediment samples (page 27) 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 pollutants of concern in the Estuary (page 83).

Q Is the contamination getting better or worse?

Answer Over the long term, the Estuary has shown significant improvements in basic water quality conditions, such as the oxygen content of Estuary water, due to investments in wastewater treatment. Contamination due to toxic chemicals has also generally declined since the 1950s and 1960s. More recently, however, the answer to this question varies from pollutant to pollutant. Mercury concentrations in striped bass, a key mercury indicator species for the Estuary, have shown little change in 30 years. PCB concentrations appear to be gradually declining based on trends observed in mussels (page 27), fish (page 26), 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 (page 24) and polybrominated diphenyl ethers (PBDEs) (page 32) are on the increase. Aquatic toxicity has declined in the past few years, possibly associated with reduced usage of organophosphate pesticides. Sediment toxicity, on the other hand, has consistently been observed in a large proportion of samples tested over the past ten years (page 27).

Q Are pollutants harming populations of organisms in the Estuary?

Answer

This critical question remains largely unanswered. There are indications that the current level of contamination is harming the health of the ecosystem, such as the frequent occurrence of pollutants above water 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 (page 79). PCB concentrations may be high enough to also cause low rates of embryo mortality in Bay birds and to affect immune response in harbor seals. Selenium concentrations appear to be high enough to cause abnormalities in early life stages of Sacramento splittail and white sturgeon (page 64). Pollutant mixtures appear to similarly affect early life stages of striped bass (page 22). Assessments of benthic communities in the marine and estuarine regions of the Bay indicate that some areas may be impacted by pollutants.

Q Do we know how to clean up the Estuary?

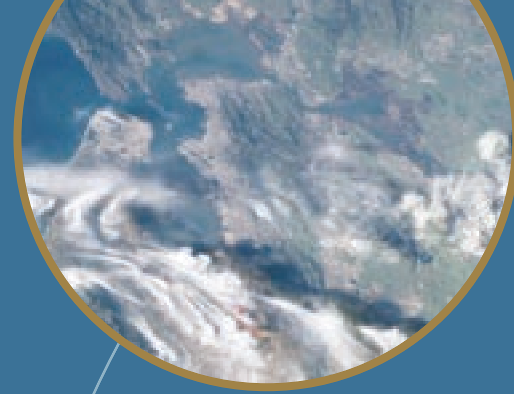
Answer

There are three general approaches to Estuary clean-up.

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

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

3. Allowing pollutants to degrade and disperse naturally is necessary. Time will always be a large part of the remedy, naturally reducing the large quantity of pollutants now in the sediments through degradation, and transport to the ocean and atmosphere. Burial in deep sediment is normally a removal process in estuaries, but due to a reduced supply of sediment to the Estuary (see page 58), burial is not occurring. For persistent pollutants found in large amounts in the sediments of the Estuary, such as mercury and PCBs, the time required to see change will be decades.



printed on recycled paper