pulse of the Estuary

Monitoring and Managing Contamination in the San Francisco Estuary 1993–99

S F E I
San Francisco Estuary Institute

About This Report

This report summarizes work to monitor current chemical contamination problems in the Estuary and watch for new problems, as well as efforts by environmental managers to reduce existing problems and prevent new ones. This report, and most of the monitoring results within, are a product of the San Francisco Estuary Regional Monitoring Program (RMP), administered by the San Francisco Estuary Institute (SFEI).

The Pulse of the Estuary is one of three Regional Monitoring Program reporting products for 1999. The second product, *RMP 1999 Monitoring Results*, is available on SFEI's web site (www.sfei.org) and includes comprehensive charts and data tables of 1999 results. The third product is the *RMP Technical Reports* collection. Each of these reports addresses a particular study or aspect of the RMP or Estuary monitoring. A list of all technical reports produced or in preparation since the last *Pulse* is found on page 28.

This is the second *Pulse of the Estuary* report. The first report, published in 2000, included important introductory topics not covered this year: *The Need to Monitor the Estuary;* and *RMP Monitoring: What, Where and Why*. These topics will be revisited in the future. New this year is information on Estuary management contributed by the staff of the San Francisco Bay Regional Water Quality Control Board (Regional Board).

Bay vs. Estuary

Although most people still refer to the expanse of water inside the Golden Gate as *San Francisco Bay*, the term *San Francisco Estuary* is becoming more common. An estuary is a place where fresh and salt water meet. San Francisco Estuary includes San Francisco Bay, the Sacramento/San Joaquin River Delta, and all waters in-between. Using the term *San Francisco Estuary* avoids the geographic ambiguity of *San Francisco Bay*, which does not have a well defined upstream boundary.

The Pulse of the Estuary

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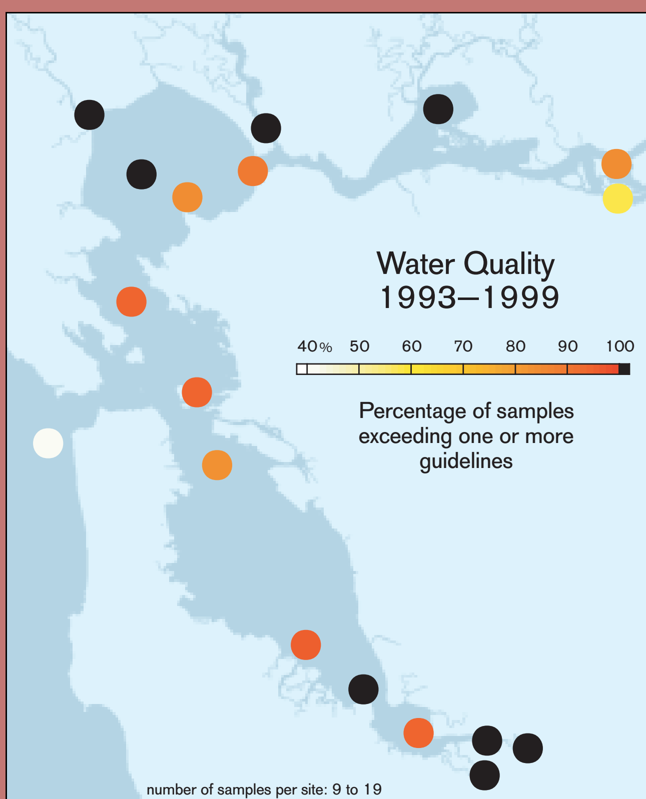
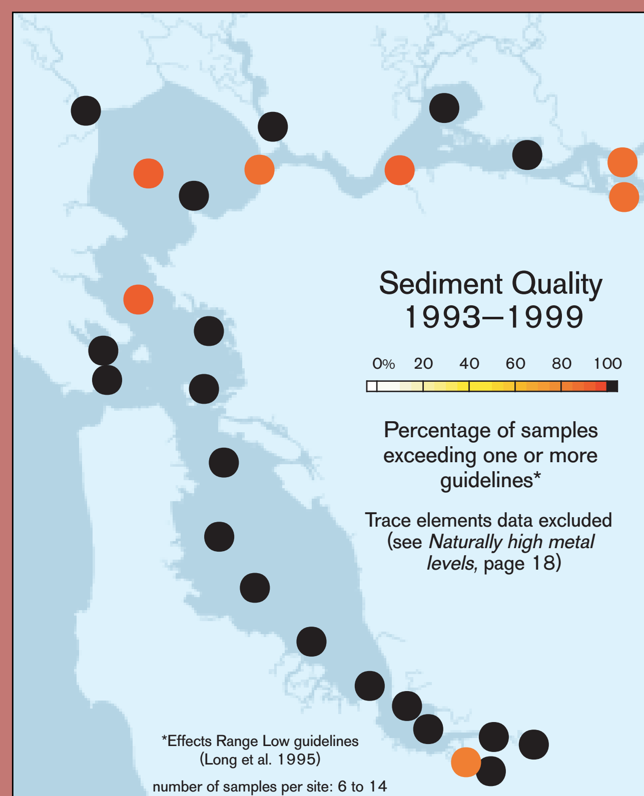
This report is also available on the web at www.sfei.org.

The cover photograph was provided courtesy of Aerial Archives, www.aerialarchives.com, an aerial photography stock agency based in San Francisco which has one of the largest collections of aerial photographs of wetlands, and also maintains a comprehensive library of historical and current vertical aerial photography including coverage of the entire perimeter of the San Francisco Bay and Sacramento River Delta. For additional information please contact Herb Lingl, Aerial Archives, 415-771-2555 or info@aerialarchives.com.

SAN FRANCISCO ESTUARY CONTAMINATION: OVERVIEW

Data collected by the RMP over the past seven years indicate that the San Francisco Estuary is moderately contaminated. Although levels of many contaminants have gone down from peaks seen in earlier decades, RMP data provide no clear indication of continued decreases. If contaminant levels are still going down, the decrease is very gradual. There are several indications that today's level of contamination is high enough to impair the health of the ecosystem. These indications include the toxicity of water and sediment samples to test organisms, and concentrations of several contaminants that frequently exceed guidelines for water, sediment and fish tissue. The remedy for this contamination includes action by Estuary managers to curb current inputs, insure excessive inputs of new chemicals are prevented, and clean up Estuary sediment where appropriate. Time is the other part of the remedy, naturally reducing the large quantity of contaminants now in the sediments through degradation, permanent burial under new, cleaner sediments, and transport to the ocean and atmosphere. For persistent contaminants found in large amounts in the sediments of the Estuary, the time required to see change will likely be decades.





These graphics summarize overall contamination levels. The left map shows the percentage of RMP water samples from each site containing any contaminants above quality guidelines (see *Guidelines,* page 8). The right map shows the percentage for sediment samples. These maps can be thought of as displaying the percentage of contaminated samples collected from each site. Sites were sampled two (for sediment) or three (for water) times a year.

Top known contamination problems

- High levels of mercury and PCBs in fish and water
- Estuary water is periodically toxic, probably due mainly to pesticides
- Estuary sediment is frequently toxic, probably due in part to heavy metals

Sites of greatest concern, sites of least concern

Contamination is not spread evenly throughout the Estuary. Overall, monitoring sites in the lower South Bay, the Petaluma and Napa River mouths, San Pablo Bay, and Grizzly Bay are more contaminated than other sites. The South Bay sloughs are particularly contaminated (however, similar sloughs in other parts of the Estuary are not monitored). Contamination in the Central Bay is lower primarily due to mixing with relatively clean ocean water. The least contaminated site is in the ocean west of the Golden Gate.

Key questions

Researchers are working to better answer these questions.

- What are the sources of contamination? How important is each?
- Are short-lived contaminant pulses released in storm runoff or agricultural drains a significant problem?
- What are the contaminants responsible for water and sediment toxicity?
- How long will it take for contamination to drop to acceptable levels?
- Are new contamination problems developing as a result of recently introduced chemicals?
- How is Estuary wildlife affected by contaminants?

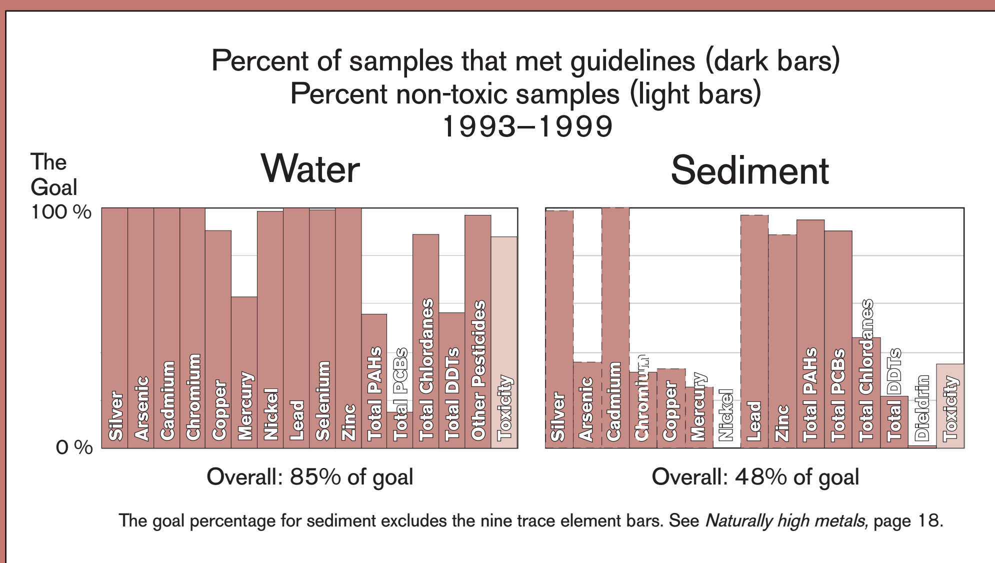
Management outlook

- The greatest potential for reducing Estuary contamination is through the identification and control of contaminant sources. Today, this is being done primarily through cleanup plans called Total Maximum Daily Loads (TMDLs—see *The Clean Water Act and TMDLs,* page 12).
- New projects in the Estuary's Regional Monitoring Program are designed, more explicitly than ever before, to provide environmental managers the information they need to reduce Estuary contamination.
- Funds for monitoring in California are increasing. Efforts to identify and reduce Estuary contamination can benefit from the information gained from other monitoring programs.

Emerging issues

- Are water contaminants such as detergent additives and pharmaceuticals cause for concern?
- How should agricultural runoff be regulated?
- Will wetlands restoration lead to more mercury in Estuary wildlife?

This bar chart indicates how close each contaminant or contaminant group is to the goal of meeting guidelines in every sample, and how often no toxicity is measured.



Note: Water quality guidelines have changed since last year's report (see Contaminant guidelines page 8). Last year's water quality graphics are not comparable to those in this report.

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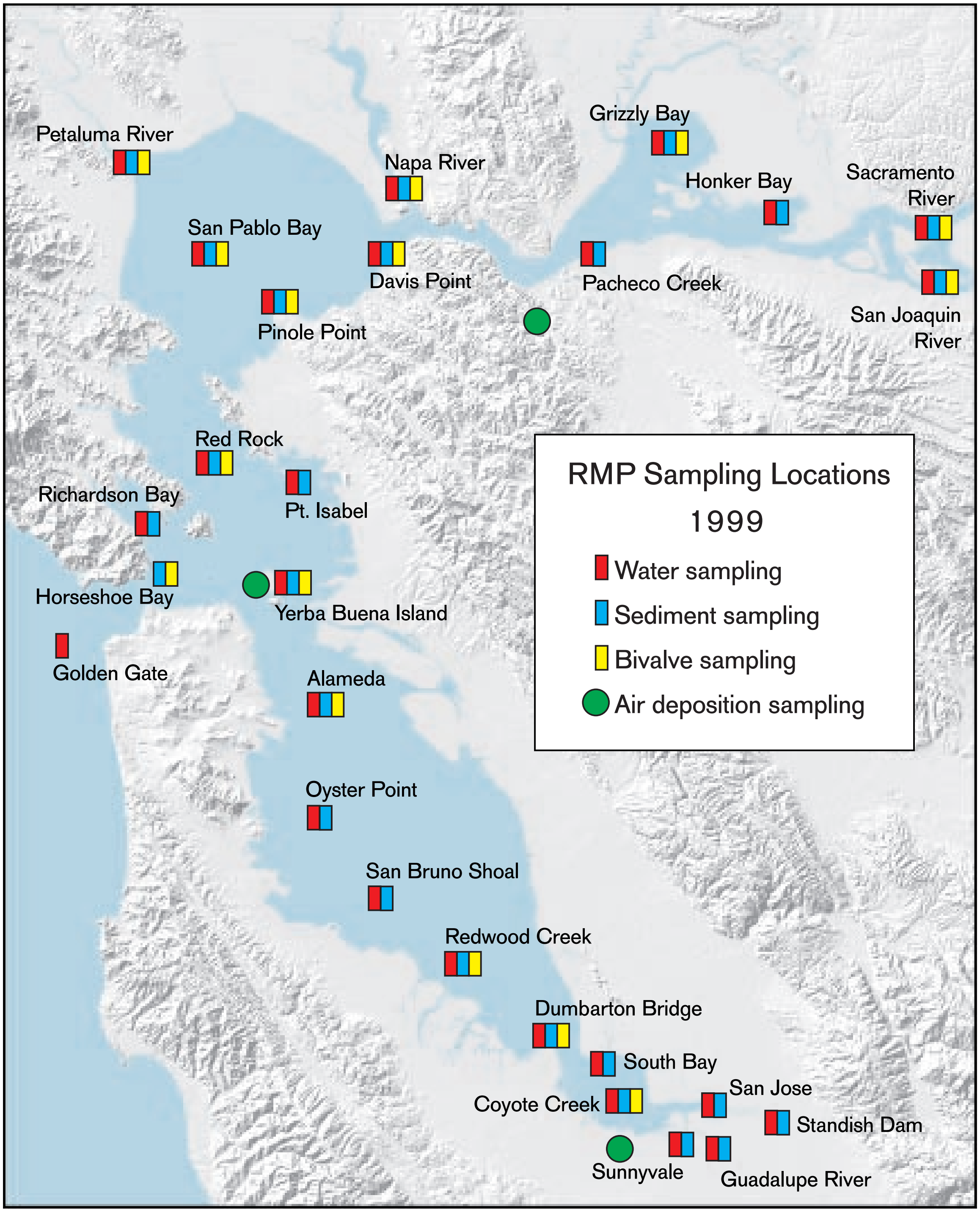
RMP Sampling Locations
1999
Water sampling
Sediment sampling
Bivalve sampling
Air deposition sampling
Petaluma River
Napa River
Grizzly Bay
Honker Bay
Sacramento River
San Pablo Bay
Davis Point
Pacheco Creek
Pinole Point
San Joaquin River
Red Rock
Pt. Isabel
Richardson Bay
Horseshoe Bay
Yerba Buena Island
Golden Gate
Alameda
Oyster Point
San Bruno Shoal
Redwood Creek
Dumbarton Bridge
South Bay
Coyote Creek
San Jose
Standish Dam
Sunnyvale
Guadalupe River

CURRENT THINKING ON CONTAMINATION

The following are working assumptions regarding contamination and the management of contamination in the San Francisco Estuary.

The Estuary is affected by contamination. There are indications that some Estuary life is adversely affected by excessive levels of mercury, pesticides, PCBs and other contaminants (SFEI 1999b; SFEI 1999c).

Management has reduced contaminant inputs. For many identified contaminants of concern, there is a good understanding of how a progressive series of management actions (such as wastewater treatment improvements) have successfully reduced the input of these contaminants from discrete sources such as industrial plants and wastewater treatment plants over the last 20 to 30 years (SFEI 2000).

Legacy contamination remains. Some of the contaminants of concern found in the Estuary today (e.g. PCBs, DDTs) entered the Estuary decades ago, and their entry has since been greatly reduced. Their continuing presence represents a key impediment to resolving contamination problems in the Estuary. These "legacy" contaminants are found in the sediments, and re-enter Estuary water via human activities and natural processes (SFEI 2000).

Unidentified contamination problems may exist. Contamination problems may exist undiscovered in the Estuary, as current monitoring does not measure many modern contaminants, such as flame retardants, detergent ingredients, plasticizers, and pharmaceuticals. See *Unidentified contaminants,* page 21.

Most of the ongoing contamination is from numerous dispersed sources. The bulk of the *ongoing* inputs of contaminants of concern comes from numerous sources scattered around the Estuary (e.g. cars, erosion, agricultural fields, gardens, small spills, etc.). Contamination from these sources is typically moved to the Estuary by rainwater via rivers, creeks and storm drains. These dispersed sources are not easily controlled through traditional regulatory approaches which focus on individual wastewater dischargers.

Contamination is best controlled by prevention. The best way to control current contaminant input to the Estuary is to focus on the dispersed contaminant sources through pollution prevention activities and watershed management (SFEI 2000).

RMP Purpose

The Regional Monitoring Program (RMP) exists to aid the management of contamination the Estuary. It does this by providing information on:

- The status and trends of contamination
- The sources and pathways of contamination and their relative importance
- The effects or potential effects that contamination is having on organisms that live in and use the Estuary, including humans

The RMP is one of several large efforts to monitor the health of the Estuary. See *Fitting the RMP into the monitoring milieu* on page 27 for more information.

RMP Origin

The Regional Monitoring Program was created in 1993 by the San Francisco Bay Regional Water Quality Control Board (Regional Board), with the help of the Estuary's wastewater dischargers and dredgers. The RMP is an innovative collaboration between the Regional Board (the local regulatory agency implementing the Clean Water Act and the California Water Code), the regulated entities that fund and participate in the Program (currently 83 wastewater dischargers and dredgers), and the San Francisco Estuary Institute (SFEI), an independent non-profit scientific research organization.

Contaminant Guidelines

Contaminant guidelines* are generally intended to indicate if water or sediment is safe. Water and sediment are safe when those things we value (e.g. wildlife, being able to eat fish we catch, or ecosystem functions) are being protected. Guidelines provide a way to connect monitoring results, which are just numbers, with judgements on the condition of the environment.

It is a daunting task to figure out just how high is too high when referring to contaminant levels in the Estuary. It is assumed that all organisms can tolerate some level of exposure to contaminants, but if that exposure gets too high, an "adverse effect" such as abnormal development or death will occur.

Guidelines are set to protect Estuary wildlife and humans from adverse effects. Of course, what is too high for some organisms may be perfectly tolerable for others. Natural factors also can have an influence; what is too high at one temperature or salinity may be tolerable at another. Contaminant mixtures can also act additively or synergistically, causing adverse effects even if the contaminant levels taken individually are safe. Given these variables, setting a proper guideline is a challenging and inexact task. Guidelines can change as new information becomes available which indicates a guideline is not protective enough or inappropriately low compared to natural concentrations. RMP results have helped determine if guidelines are set appropriately. Most guidelines were created for use throughout the state or

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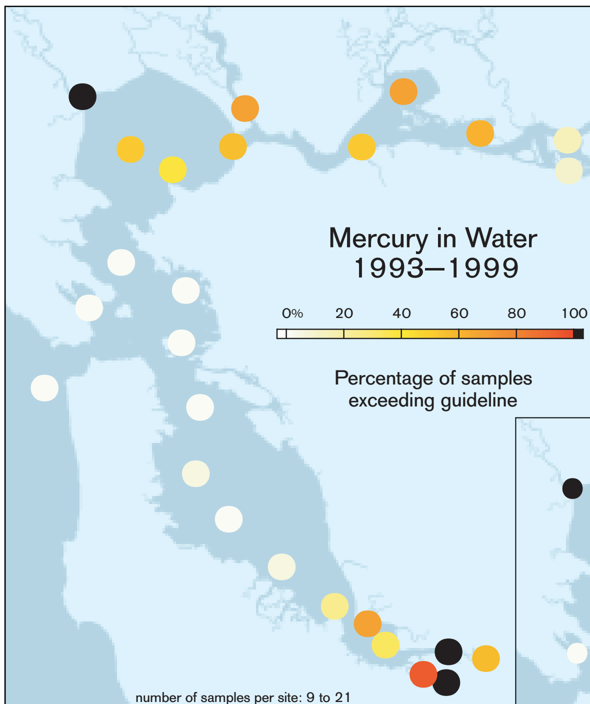
* In this report, the general term *guideline* is used to refer to several types of environmental quality benchmarks, from legally enforceable water quality *criteria* to unofficial benchmarks such as the Effects Range values for sediment (Long *et al.* 1995).

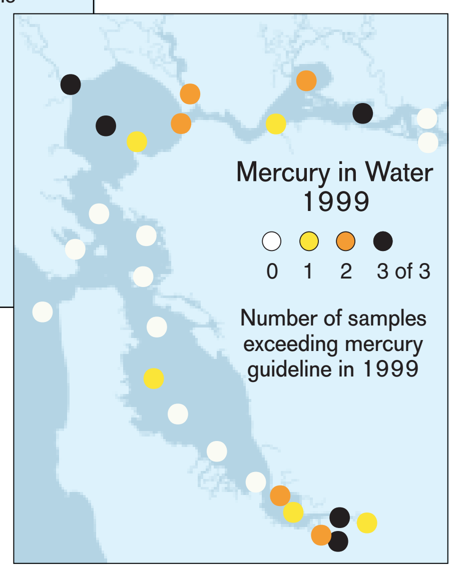
Problem: High mercury levels in water and fish

Mercury, a known neurotoxicant, has the potential to harm Estuary fish and the humans and wildlife that consume them.

Status and trends

Mercury frequently exceeds guidelines in fish such as striped bass and leopard shark. Water guidelines for mercury are exceeded regularly in the South Bay. Data from the RMP indicate mercury levels in water have been stable over the last seven years. The expectation for the future is that mercury concentrations will drop very gradually. It may take decades to see significant change, as large masses of mercury are found in Estuary sediments and in the sediments carried by rivers leading to the Estuary.





Cause

California's long history of gold and mercury mining has resulted in large deposits of mercury-laden sediments at the bottom of the Estuary, and mercury in upstream soils and sediments continues to wash into the system. Mercury from upstream, entering via the Sacramento and San Joaquin Rivers, is probably the largest input (Abu-Saba and Tang 2000). Although the input is large, it is a relatively dilute input. Samples from these rivers thus tend to have lower mercury concentrations than some other sites (see figures on this page). The second largest input is likely erosion and resuspension of contaminated sediments already in the Estuary. The third largest input is local sources. Of these, the largest is probably the inactive mine at New Almaden (see *New Almaden*

Mine, this page*)*. Another significant pathway (see *Source vs. Pathway*, this page) for local inputs is the runoff from urban areas. Additional, likely smaller, mercury pathways include discharge from industry, municipal wastewater treatment plants, and direct entry to the water from the atmosphere.

A study begun in the summer of 1999 indicates that the amount of mercury directly deposited from the air onto the Estuary could be up to two times greater than the amount contributed by wastewater dischargers. Air deposition of mercury onto the Estuary's watershed lands is likely an important part of the input from rivers, creeks, and storm drains. The biggest source of airborne mercury is probably incineration and manufacturing, followed by florescent lamp breakage and vehicle emissions.

The total amount of mercury entering the Estuary is actually of secondary concern to the production of one particular form, known as methylmercury, produced through bacterial action in sediments and especially prone to uptake by organisms (see *Mercury*, this page).

Effects

Mercury may be a cause of abnormal development of bird eggs in the Estuary. The San Francisco Bay Regional Water Quality Control Board (Regional Board) through CALFED is currently conducting a study to investigate this. The RMP is planning

Mercury (Hg)

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

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

Mercury is found in several forms, some of which have much greater potential for harm than others. Methylmercury (CH_3Hg^+) is the form of greatest concern and is produced by bacterial action in sediment.

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

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

The legacy of the New Almaden mercury mine

Runoff from the New Almaden Mine, once the largest producer of mercury in North America, drains into the Guadalupe River, which flows into the South Bay. Data from the RMP show that mining at New Almaden has contaminated sediments throughout the South Bay. Although New Almaden is currently managed as a Superfund site and much of the site has been covered, contaminated sediments pervade the Guadalupe River system. This is confirmed by panning sediments from the bed and banks of the Guadalupe River and Alamitos Creek. Drops of liquid mercury and chunks of mercury ore can be found in samples taken anywhere from New Almaden down to San Jose.

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nation, not specifically for the Estuary. Guidelines specific to the Estuary are being developed for some contaminants.

For water, guideline development incorporates both laboratory studies and field observations, and is designed to protect a particular set of qualities we value, known in the California Water Code as "beneficial uses." Water guidelines are intended to protect most organisms most of the time, not all organisms all of the time. The Regional Board, a state agency, sets water guidelines with guidance from the U.S. Environmental Protection Agency. In 2000, the water guidelines for the Estuary were revised. The revised values, collectively known as the California Toxics Rule, are used in this report.

For sediment, the guidelines used in this report ("Effects Range Low" values or ERLs) are based on a study that compiled many observations of adverse effects on organisms in laboratories and natural settings around the world (Long *et al.* 1995).

For fish, the guidelines, calculated by SFEI with the help of state and federal agencies, aim to protect human consumers and consider what is known about animal responses to ingesting contaminants.

Source vs. Pathway

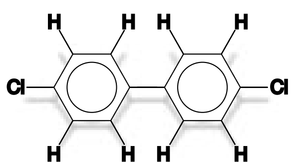
In considering the entry of contaminants into the Estuary, it is important to understand the difference between a *source* and a *pathway*. "Sources" are activities leading to the release of contaminants into the environment, such as combustion of gasoline in a car engine or application of a pesticide to an agricultural crop. Sources are distinct from "pathways", which are the routes through which contaminants enter the Bay, such as urban runoff, streams and rivers, deposition from the atmosphere, or wastewater discharge. Pathways are sometimes misconstrued as sources.

Polychlorinated Biphenyls (PCBs)

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

Growing awareness of the environmental impacts of PCBs, including their persistence and accumulation in animal tissue, led to a ban on their sale and production in the United States in 1979.

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



studies to better document the ecological effects of contaminants such as mercury. Although the effect the Estuary's mercury contamination may be having on human residents has never been measured, health officials have determined that the level of mercury in fish is high enough to potentially harm the health of those who eat fish from the Estuary.

Cures

In order to help minimize human exposure to mercury, the state Office of Environmental Health Hazard Assessment (OEHHA) posted a consumption advisory which recommends consumers limit the amount of fish they eat from the Estuary (see *Fish Consumption Advisory,* next page) (OEHHA 1994).

In an attempt to reduce mercury levels in the Estuary, the Regional Board has prepared a cleanup plan known as a Total Maximum Daily Load (see *The Clean Water Act and TMDLs,* page 12). The mercury TMDL is scheduled to be in effect by 2002 (Abu-Saba and Tang 2000).

The Estuary's ongoing failure to meet water quality guidelines is the main impetus for the TMDL process. There is scientific certainty that mercury water quality guidelines are violated in the Estuary. The policy questions at hand are: to what degree are those violations due to *controllable water quality factors*, and what can be done?

The TMDL analysis indicates that the input of mercury via Central Valley sediments carried by rivers is likely the largest source of mercury to the Estuary. However, input from the Central Valley is not a controllable water quality factor, at least not within the jurisdiction of the San Francisco Bay Regional Board, so no reduction is called for in the TMDL.

In contrast, elevated mercury in South Bay sediments is mainly the result of erosion of New Almaden mine tailings on private and county-owned lands, design and maintenance of flood control projects within the Guadalupe River system, and remobilization of polluted sediments during construction and new development in the Guadalupe River floodplain. Those watershed processes can be regulated by the San Francisco Bay Regional Board, and are therefore controllable water quality factors. Accordingly, the TMDL designates the Guadalupe River watershed as the mercury source needing the greatest reduction.

Effective control of the mercury problem requires control of methylmercury production, as methylmercury most readily accumulates in animals. Reducing mercury inputs is an important part of this management strategy, because the production of methylmercury is in part driven by total mercury inputs. But understanding where and how mercury is converted to methylmercury is also important for achieving the ultimate goal of removing harmful effects.

Problem: High PCB levels in water and fish

The widespread presence of polychlorinated biphenyls (PCBs), a known group of carcinogens, has the potential to harm humans and wildlife that consume fish from the Estuary. In addition, PCBs may be harming the fish themselves.

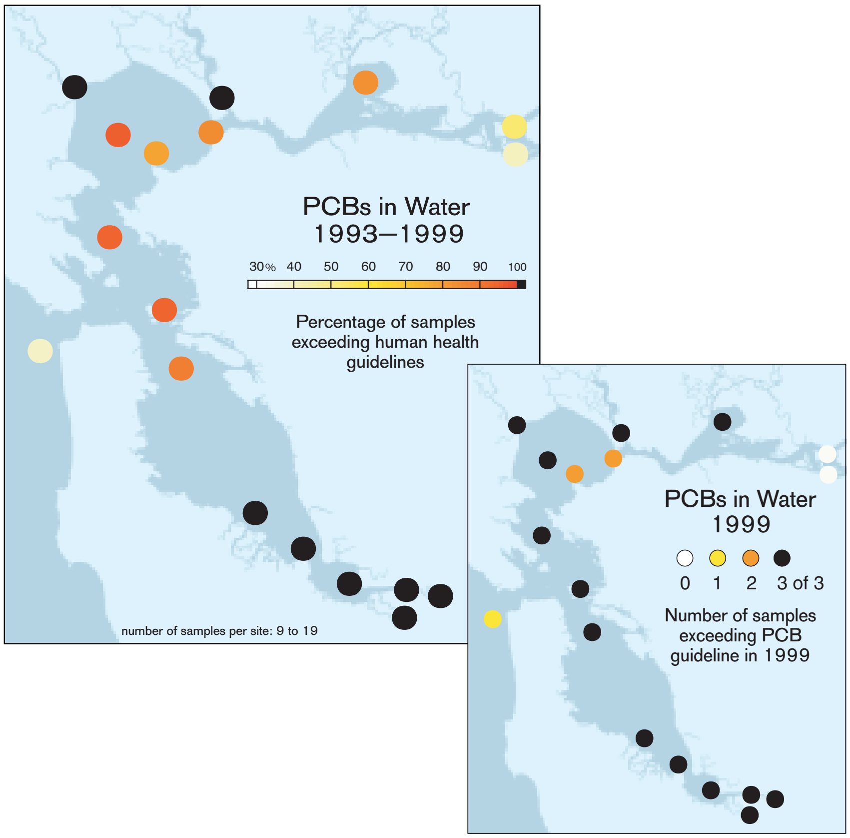
Status and trends

While PCB levels have dropped from their maximum in the early 1970s, there has been no clear trend in recent years.

The expectation for the future is that PCB concentrations will drop very gradually. It may take decades to see significant change. Estuary sediments contain PCBs that are stirred into the water by waves, tides, river currents, dredging and other processes.

Cause

Leakage from or improper handling of equipment containing PCBs has led to widespread contamination of Estuary watersheds, and subsequently the Estuary itself. A PCB budget developed for the Estuary suggests that PCB inputs continue today, in



spite of the ban on their sale and production in 1979 (SFEI 1999c). Much of this input is believed to be movement of PCBs from contaminated land to the Estuary via rivers, streams, storm drains, and the air. However, there is analytical evidence of "fresh" PCBs still entering the Estuary, suggesting that the escape of PCBs from industrial equipment or related sources continues today (Johnson *et al.* 2000).

Effects

There is reason to believe that PCBs have affected starry flounder reproduction (Spies *et al.* 1988; Spies and Rice 1988), and PCB levels that appear high enough to cause harm have been measured in cormorant eggs and harbor seals (Davis *et al.* 1997; Young *et al.* 1998). The RMP is planning studies to better document the ecological effects of contaminants such as PCBs. Although the effect the Estuary's PCB contamination may be having on human residents has never been measured, health officials have determined that the level of PCBs in fish is high enough to potentially harm the health of those who eat fish from the Estuary.

Cures

In order to help minimize human exposure to PCBs, OEHHA posted a consumption advisory which recommends consumers limit the amount of fish they eat from the Estuary (see *Fish Consumption Advisory,* this page) (OEHHA 1994).

Fish Consumption Advisory

The following text is taken from the interim fish consumption advisory for San Francisco Bay. The full text is available at www.oehha.org/fish/general/99fish.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).

This advisory does not apply to salmon, anchovies, herring, and smelt caught in the bay; other ocean sport fish; or commercial fish.

In an attempt to reduce PCB levels in the Estuary, the San Francisco Bay Regional Water Quality Control Board is preparing a TMDL (see *The Clean Water Act and TMDLs,* this page). The main impetus for the development of the PCBs TMDL is the interim health advisory on eating fish caught in the Bay.

There are a number of challenges in the development of the San Francisco Bay PCBs TMDL. As with many other legacy contaminants, there is a large amount of PCBs already in the Estuary, much of it deep in the sediment. An important outstanding issue is the movement of PCBs between deep sediments, surface sediments and the water. Legacy PCBs in deep sediments could be a major source of PCBs to the water, if the contaminants diffuse upward or if deep sediments are disturbed.

Current knowledge of sources of PCBs to the Estuary is not refined enough to determine the important sources or to eliminate any source as insignificant. The upcoming efforts for the TMDL will focus on quantifying PCB inputs from wastewater, urban runoff, the air, and contaminated sediments.

The exchange of PCBs between sediments, the water and the Estuary food web needs to be better understood in order to select the most appropriate PCB sources to reduce as part of the TMDL. It is important to know, for example, if capping contaminated sediment with clean sediment is a good solution. SFEI will model the food web to help determine how PCBs are transferred from the sediment and water to fish prey and fish (see *Analyzing contaminant movement and storage* on page 23). This will help identify how and where to act to best resolve the ultimate concerns such as fish contamination.

Understanding PCBs in deep sediment, PCB sources, and food web dynamics are the current top priorities for the preparation of the TMDL. This work will help determine the best remedies for the PCBs already in the Estuary and for the control of ongoing sources to the Estuary. The Regional Board is working closely with SFEI and other interested parties as the TMDL is developed.

The Clean Water Act and TMDLs

The Clean Water Act recognizes that every body of water has uses that are valued and worth protecting. The 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, under traditional management, 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 "303d 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 waterbody, determining the total input the waterbody can handle, and designating particular inputs that need reduction.

Organophosphate pesticides (OPs)

Growing recognition of the environmental threat posed by organochlorine pesticides such as DDT, combined with insect resistance, led to their gradual replacement by organophosphate pesticides. Although regarded as much less of a threat than organochlorines, organophosphates have raised their own set of concerns. Organophosphate pesticides such as diazinon and chlorpyrifos (Dursban) appear to be the active agents in some of the Estuary water samples that cause adverse effects in laboratory organisms.

Organophosphate pesticides do not persist for decades as organochlorines do, so contamination problems can be turned around relatively quickly with appropriate management to prevent continued input of the pesticides to the water.

Recent management action has resulted in a planned phase-out of diazinon and new restrictions on chlorpyrifos use (see *Cures* under *Toxic Water,* next page).

Problem: Toxic water

When Estuary water can harm or kill organisms in the lab (see *Toxicity testing* sidebar, next page), it indicates that life in the Estuary is potentially being harmed or killed. Trouble for one group of organisms can have a domino effect on other organisms linked by the Estuary food web.

Status and trends

Most occurrences of water toxicity appear to be related to rainfall. While most of the water sampled by the RMP is not toxic, water from sites in the North Bay and South Bay that coincided with significant rainfall has frequently been toxic (SFEI 1999b). During two periods in 1998, three consecutive samples taken at two to three day intervals in the North Bay were all toxic, suggesting that extended periods of toxicity occur.

Other studies on the Sacramento and San Joaquin rivers have found that water on some sections of those rivers is frequently toxic (Foe and Conner 1991a; Foe and Conner 1991b; Foe

1995; Ogle *et al.* 1998), and a study on storm water runoff from urbanized locations in the Estuary determined that most samples were toxic (S.R. Hansen and Associates 1995).

Over the last three years, storm-related water toxicity in the Estuary appears to be decreasing, at least for the primary test organism (the shrimp *Mysidopsis bahia*). This trend matches the reported decline in use of organophosphate pesticides (OPs). However, during this time period, the use of other pesticide types such as pyrethroids has increased. It is possible that the test organism used by the RMP is not sensitive to pyrethroid pesticides and that the decreasing toxicity trend does not represent true improvement of the Estuary. Recent tests using juvenile fish suggest that toxicity unrelated to OPs is occurring.

Cause

To date, attempts to determine the cause of the toxicity (see *Toxicity testing* sidebar, this page) observed in RMP water samples are not conclusive. In most cases the causes remain unknown, but in some cases pesticides are implicated. Extensive studies of the Sacramento and San Joaquin rivers, and a study of storm drains in the Estuary, indicate in most cases that pesticides are the toxic agent (Deanovic *et al.* 1996; Deanovic *et al.* 1998; Foe *et al.* 1998; S.R. Hansen and Associates 1995). The type of pesticides implicated, organophosphates, are currently used in agriculture and by residents and businesses throughout the region. Rainfall moves these pesticides from the plants and land where they were applied into the Estuary, where minute quantities can make the water toxic. Once in the water, OPs are generally believed to degrade relatively rapidly into harmless compounds, in contrast to organochlorine pesticides such as DDT (now banned), which are much more resistant to degradation. However, serious harm to Estuary life may occur before the OPs degrade.

Water toxicity found in the North Bay is thought to be due in most cases to runoff from agricultural fields in the Central Valley and Delta. This assertion could be further examined through studies to identify the toxic agent or agents in RMP samples and compare the timing of pesticide applications with incidents of toxic water. Pesticide application information is currently difficult to compile in the timely manner needed to conduct such a study (SFEI 1999c).

Toxic water in urban storm drains is likely due to residential, business, and local government use of OPs.

Effects

Toxicity test results suggest Estuary water has the potential to harm organisms in the Estuary. The toxic episodes observed coincide with the presence of early life stages of many of the fish populations that are currently in decline in the Bay, including delta smelt, Chinook salmon, steelhead trout, and green sturgeon. The reduction of North Bay zooplankton, thought to be mainly the result of an introduced clam, may also be related to water toxicity. The RMP is planning studies to document the ecological effects of the Estuary's water toxicity.

Cures

In 2000, the U.S. Environmental Protection Agency (EPA) acted to reduce the use of two key OP pesticides, chlorpyrifos and diazinon. The EPA banned the use of chlorpyrifos in home and garden applications, and restricted its use in agriculture. The EPA also reached an agreement with the manufacturer of diazinon to phase out its production over the next four years. Meanwhile, local agencies around the Estuary are engaged in public information campaigns to reduce the use and improper disposal of OPs by homeowners and businesses.

Toxicity testing

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

A more direct approach to assessing potential harm, which avoids many of the difficulties of interpreting contaminant concentrations, is to expose organisms (such as mussels or shrimp) to Estuary water or sediment in the laboratory and look for adverse effects such as developmental abnormalities or death. If a clear adverse effect is seen, it is assumed that harm is occurring in the Estuary itself. However, this conclusion is open to some contention, as some of the laboratory organisms used in RMP tests do not actually reside in the Estuary, but are specified by standard toxicity test protocols. The RMP is considering increasing its use of resident species to address this issue.

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

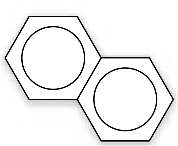
At the request of interest groups, the Central Valley Water Quality Control Board is considering whether agricultural irrigation wastewater discharges should be subject to water quality permits, as are industrial and municipal wastewater discharges. Currently, these discharges are exempt. If this exemption is discontinued, agricultural groups may have to comply with certain pollution prevention rules in exchange for a permit to discharge their used irrigation water.

Questions have been raised by some regarding the widespread use of pesticides and the concurrent need to conduct expensive monitoring programs subsidized by taxes or sewage fees. Regardless of any changes brought about by such questioning, while pesticide use is widespread, the RMP and other monitoring programs can watch for and inform the community of potential problems. To monitor effectively at a time when the types of pesticides in use are changing, it is important that the organisms used in toxicity tests—in addition to being representative of the Estuary ecosystem—are sensitive to the chemicals in use.

Polycyclic aromatic hydrocarbons (PAHs)

PAHs are ubiquitous in the environment, forming whenever organic substances are exposed to high temperatures. PAHs form when plant material is burned. A forest fire, a log in a fireplace, charcoal in a grill, and car exhaust are sources of PAHs. Crude and refined petroleum products contain PAHs. PAHs can be suspended in the air and deposit directly onto the surface of water during rainfall. PAHs also attach to dust particles that can settle on the surface of the water or the ground. Rain water can wash particles from streets and parking lots into channels, creeks, and ultimately the Estuary. Higher concentrations of PAHs are found in urban areas.

When PAHs enter the Estuary, they accumulate in sediments and organisms at the bottom of the food web. They can elicit a wide variety of toxic effects in aquatic species, including impaired survival, growth, metabolism, reproduction, immune function, and photosynthesis. Due to the tendency of most PAHs to accumulate in sediment, they pose an acute hazard primarily to invertebrates living at the bottom of the Bay. These organisms are an important food source for many species of fish (see Figure 2 on page 24). PAHs, particularly the larger PAH molecules, are among the most potent carcinogens known.



Problem: Toxic sediment

When Estuary sediment can harm or kill organisms in the lab (see *Toxicity testing* sidebar, previous page), it indicates that life in the Estuary is potentially being harmed or killed. Sediments provide habitat to many Estuary organisms that are important parts of the Estuary food chain.

Status and trends

Over the past seven years, 65% of RMP sediment samples were toxic to at least one of two lab organisms (see figures, next page). Year to year, the proportion of toxic sediment samples ranged from 38% to 79%, with no clear overall trend. At one site, Yerba Buena Island, the occurrence of toxic sediments appears to be increasing. Samples taken during the rainy season are more likely to be toxic than those taken during the dry season.

Sediment toxicity is likely to remain high for many years to come, given the tendency for contaminants to accumulate in the sediment, the resistance of many sediment contaminants to degradation, continued inputs, and the slow rate of the burial process that sequesters contaminated sediment.

Cause

Analyses to identify the cause of the sediment toxicity have yielded a variety of answers, probably in part due to the complex mixtures of chemicals involved. Different contaminants are implicated at different sites at different times. One or more metals are implicated in many cases. It is likely that a combination of contaminants is often responsible (Thompson *et al.* 1999; Anderson *et al.* 2000; Phillips *et al.* 2000).

Measurements of contaminant levels in sediment show the legacy pesticides DDT and chlordane contaminate the entire Estuary. Also of concern, particularly in the South Bay, are combustion by-products known as PAHs (see sidebar, this page). However, test results in some cases appear to exonerate these compounds as causes of sediment toxicity. Work to identify the contaminants continues.

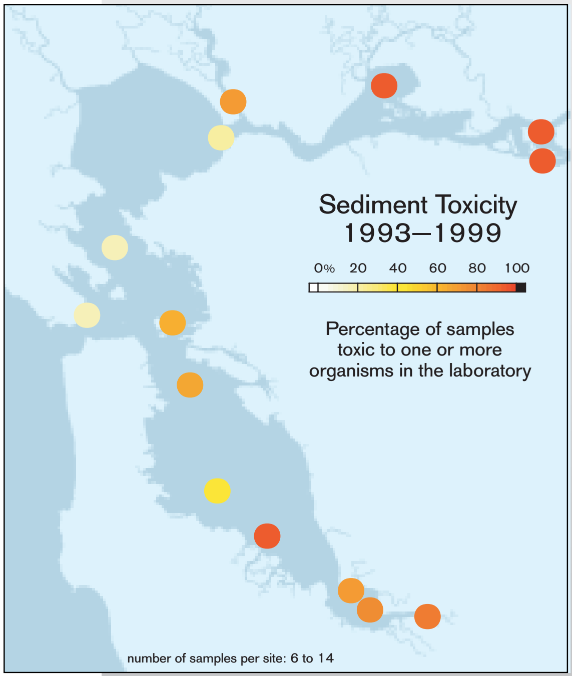
Effects

Toxicity tests clearly show harmful effects of Estuary sediment on organisms in the laboratory, but data on actual effects on Estuary life are limited. It is difficult to link the condition of organisms in the field to any particular environmental variable. Some of the communities of benthos (sediment dwelling organisms) monitored by the RMP show evidence of contaminant impacts, such as reductions in the populations of contaminant-sensitive species. Changes in benthos can impact the many benthic predators in the

Estuary. The reproduction of an introduced clam appears to be affected by sediment contaminants in the heavily industrialized Carquinez Strait area (Brown and Luoma 1999). More documentation of the ecological effects of the Estuary's sediment toxicity would allow managers to better determine the urgency of the problem.

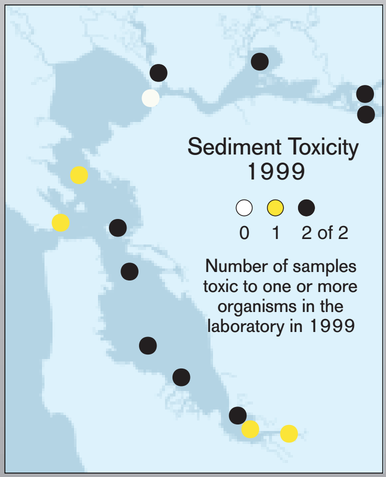
Cures

To date, the Regional Board has identified at least 16 sites where contaminant releases have resulted in a legacy of sediment contamination, most of which are associated with current or former industrial facilities, former military bases, or sewer overflows.



Unfortunately, among the various areas of regulatory concern for the Board, investigation and cleanup of contaminated sediment sites has been among the slowest to develop. Perhaps the foremost reason is the common-sense consensus that the original land source(s) of contamination must be cleaned up before any lasting estuarine sediment cleanup can be realized. Other reasons include: difficulty in identifying responsible parties; the potential high costs of cleanup; the possibility that a cleanup attempt will do more harm than good; and uncertainties regarding contaminant uptake by organisms, the meaning of toxicity results, and the ultimate fate of the contaminants in the environment. The TMDL process (see *The Clean Water Act and TMDLs,* page 12) will likely help guide decisions about sediment contamination, and may lead to funding to cleanup sites where a responsible party cannot be identified.

In the case of many sites, the land cleanup is completed or well underway, and the contaminated sediments are now being addressed. One unresolved issue is how to determine exactly which sediments pose an excessive risk to the environment. The solution likely involves a "weight of evidence" approach employing multiple measurements, such as sediment contamination levels, toxicity, and organism contamination levels, to determine if action is warranted. At some sites, contaminated sediments may naturally become buried or "capped" by new sediment, and cleanup may not be necessary. The RMP will conduct a study to better determine if contaminated sites naturally and permanently cap and should simply be monitored rather than subjected to an engineered cleanup. Since a decision to cleanup a site can result in large financial burdens and impacts to the environment, small investments in capping studies are likely to have significant benefits in the future.



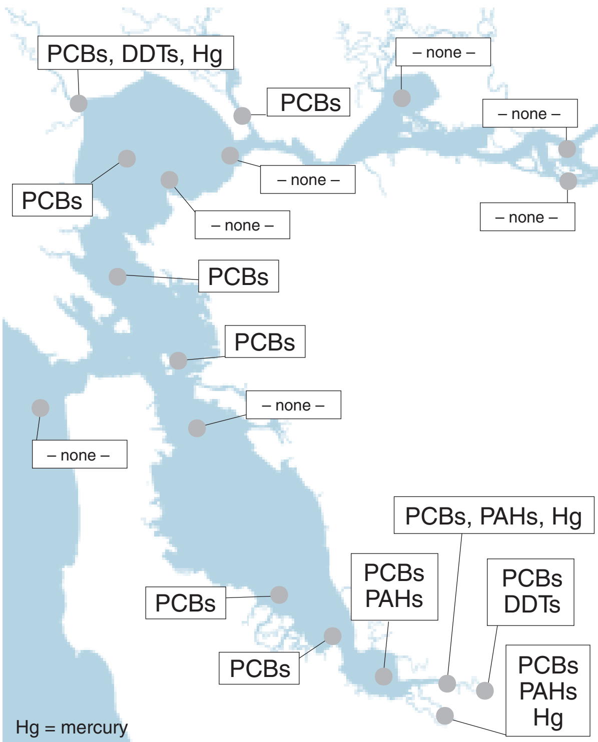
If a site requires action, there are two possibilities: dredging (removing the contaminated sediment) and in-place containment. Contaminated sediment dredged from a site usually requires costly disposal as hazardous waste. Treatments to remove contaminants are being researched, but the mixtures of contaminant types that are usually found at these sites can limit the effectiveness of any single treatment method. The cost of any action is a significant concern for responsible parties, and they may be willing to address only the most obvious pollutant impacts using the least costly method possible. However, long-term monitoring of cleaned sites should reveal if the chosen remedy is adequate or if the responsible party needs to take additional actions.

Sediment contamination has been remedied at least three sites in the Bay, with varying degrees of success. In general, the two remedies that relied upon dredging alone do not appear to have been as effective as the one that relied upon a combination of dredging and containment. However, no one particular remedy is best suited to all site conditions. Additional studies in progress and in planning by the Regional Board and the RMP should clarify some of the uncertainties and provide useful information about remedy selection at all sites.

Water

Status

Based on comparisons to the latest guidelines (see *Guidelines*, page 8) concentrations of one metal and several organic chemicals have frequently exceeded water quality guidelines in the RMP: mercury, PCBs, DDTs, chlordanes, and PAHs (see figure, this page). PCBs have the worst track record of all of these problem contaminants.



Water contaminants that exceed their guideline more than 90% of the time (by location, 1993–1999).

Some locations in the North Bay (particularly the mouth of the Petaluma River and San Pablo Bay) and all three locations in the South Bay sloughs exceed water quality guidelines more frequently and with more contaminants than other locations (see figure, this page; and *Water Quality* figure, page 3). All samples from these sites contained one or more contaminants above guidelines. In general, river mouths and sloughs appear more contaminated than open water areas.

Nearly all RMP monitoring has occurred during years of above average river flow, and results may be biased in unknown ways toward such conditions (Cloern *et al.* 1999).

Trends

Since the RMP has only been in place since 1993, it is not possible to draw conclusions about long-term trends using RMP data alone. However, when RMP data are considered together with data from earlier monitoring efforts, such as the State Mussel Watch Program, sufficient data are available for a meaningful discussion of long-term trends.

Mussels readily accumulate organic compounds such as PCBs and DDT, and can be used as indicators of water quality. PCB concentrations in mussels dropped sharply in the early 1980s, then showed no perceptible change from 1982–1999. Concentrations of the organochlorine pesticides DDT, chlordane, and dieldrin generally were high in 1980, dropped sharply in 1981, and have declined very little since about 1988.

"PCB concentrations in mussels dropped sharply in the early 1980s, then showed no perceptible change from 1982–1999."

In spite of drastic reductions in the input of metals achieved by the ban on leaded gasoline and improvements in wastewater treatment, concentrations of lead and other metals in water have changed little in the last 20 years (Flegal *et al.* 1996). In the case of lead, inputs to the environment from leaded gas are still working their way downstream, and will be for decades (Steding *et al.* 2000).

Sediment

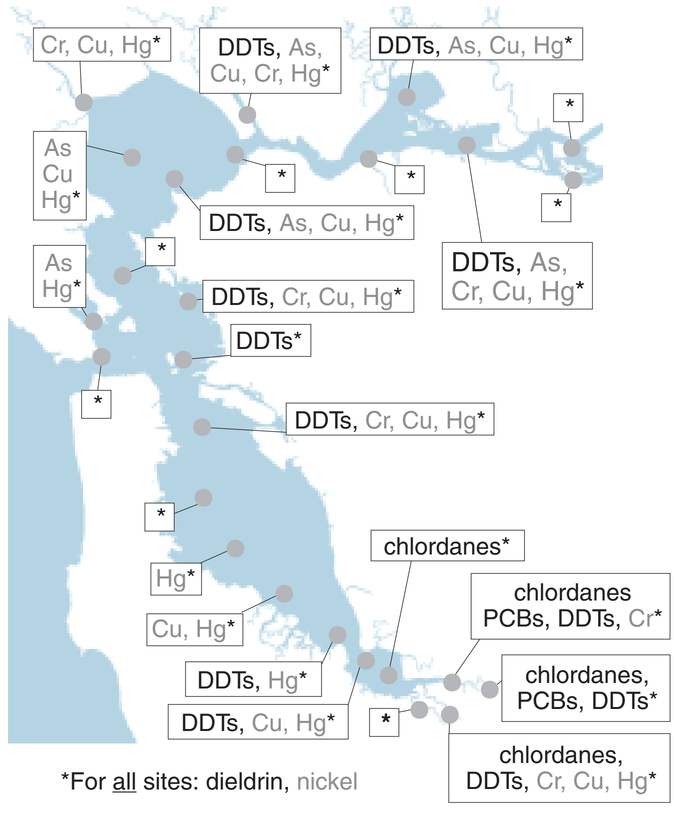
Status

At most sites, several trace elements (arsenic, chromium, copper, nickel, mercury) and organic compounds (DDTs, chlordanes, some PAHs) frequently exceed the guidelines indicating *possible* harm to aquatic life (guidelines known as "ERLs"). Nickel usually exceeds the guideline indicating *probable* harm to aquatic life (ERMs). However, many trace elements are naturally at high levels in Estuary sediment, and may not be a problem (see *Naturally high metal levels*, page 18).

DDTs are found at levels of concern in sediment throughout the Estuary. This is due to its widespread use prior to its ban in 1972. Additional DDTs may be entering the Estuary today as historically contaminated soils and sediments enter from upstream. Chlordanes, another widespread sediment contaminant, share a similar history to DDTs, but the banning of chlordanes (used primarily in termite control) did not take place until 1988.

PAHs are another prominent group of sediment contaminants. Unlike DDTs, chlordanes, or PCBs, PAHs are still being actively created, and enter the Estuary in a wide variety of ways. The combustion of fossil fuel is one of the primary sources of PAHs to the Estuary. Combustion particles containing PAHs settle directly on the water, or on the land where they are washed via streams and storm drains to the Estuary. PAHs from refinery accidents and oil spills have also contaminated parts of the Estuary.

Sites in the sloughs and creeks of the South Bay usually had the most guideline exceedances (see *Sediment Quality* figure, page 3). The lowest sediment contaminant concentrations and fewest guideline exceedances occurred at sandy sites such as Red Rock and Davis Point. About 70% of the sediment samples collected by the RMP were toxic to organisms in the laboratory (see *Problem: Toxic sediment* on page 14).



Sediment contaminants that exceed their guideline more than 90% of the time (by location, 1993–1999). Shaded text indicates guideline uncertainty, see *Naturally high metal levels*, next page.

Measurements of wetland sediment at Petaluma and China Camp marshes frequently found contaminant concentrations slightly higher, and occasionally 2 to 10 times higher, than those of San Pablo Bay, the closest non-wetland RMP sampling location (Collins and May 1997).

Trends

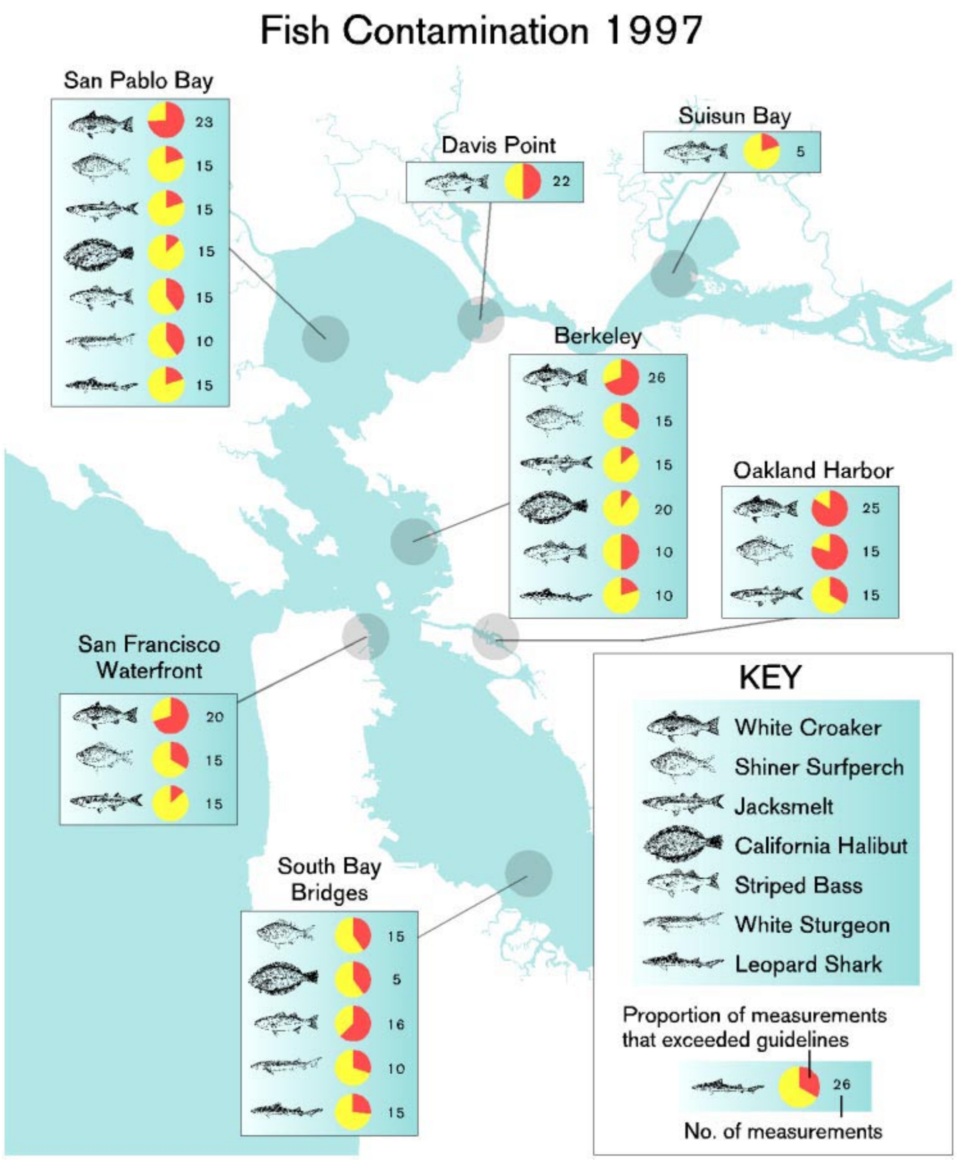
There were few significant Estuary-wide trends in sediment contamination discernible over the last seven years. Chromium and nickel appear to be increasing, but this is thought to be a natural event due to increased rainfall (see *Naturally high metal levels*, next page).

Sampling at a series of depths in the sediment can reveal trends in historical contamination levels. Such sampling indicates that most contaminants have dropped from peak levels seen in the 1960s and 1970s (Venkatesan *et al.* 1999), probably in response to wastewater treatment improvements, product bans, and other regulatory actions. Nickel, on the other hand, appears to have remained at similar levels since prior to industrialization, due to is presence in rock in the watershed.

Fish

Status

Fish contamination guidelines referred to as "screening values" have been developed for the Estuary following the guidance of the EPA. Exceedance of the screening values indicates potential human health concerns and the need for further study. In 1997, mercury and PCBs exceeded screening values in over 50% of the fish tested from San Francisco Bay. A small number of fish samples were tested for dioxins, and all seven of these samples exceeded the dioxin screening value. Screening values for DDTs, chlordanes, and dieldrin were exceeded in 15 to 37% of the samples tested.



This illustration shows the proportion of 1997 RMP fish sample measurements that met guidelines (screening values). The yellow pie slices indicate the proportion of measurements that met guidelines, the red slices, the proportion that exceeded guidelines; more yellow is better.

Naturally High Metal Levels

Because of the types of soils and rock within its watershed, Estuary sediment naturally contains large amounts of several metals and other trace elements, particularly nickel and chromium. Although all metal levels have been increased by human activities, certain metal levels that would indicate a problem in many water bodies appear to be causing no harm in the Estuary. Thus, comparing local metal concentrations to guidelines not specifically developed for the Estuary may be misleading, and the traditional goal of reducing concentrations below guidelines could be impossible to achieve. A further complication is that many metals have several common forms which differ markedly in their potential to cause harm, yet currently monitoring does not measure each form independently. Given these issues and the lack of Estuary-specific sediment metal guidelines, evaluating RMP sediment metal data in terms of Estuary health is difficult. The sediment map on page 3 excludes data for metals.

These issues should be resolved. The Estuary needs appropriate guidelines for all metals, and work to develop these has begun. Knowledge of pre-industrial metal concentrations deep in sediment can aid this work.

Some species had higher contaminant concentrations than others. Organic contaminants such as PCBs and pesticides were highest in white croaker and shiner surfperch, while mercury was highest in leopard shark and striped bass. These differences are due to fish diet, location, metabolism, body composition, and other factors.

In several cases, the fish from Oakland Harbor contained higher contaminant concentrations than those from other locations, especially for PCBs and chlordanes (see figure, previous page). The Oakland site was the closest of any to an industrialized area.

A 1998 study of largemouth bass and white catfish in the Delta and upstream rivers produced similar results. About 50% of the fish sampled were over the mercury screening value, about 30% over the PCB screening value, and about 23% over the DDT screening value. The central Delta was found to contain “cleaner” fish overall than the rest of the Delta and the upstream rivers (Davis *et al.* 2000).

Trends

Fish were sampled in 1994 by the Regional Board and in 1997 and 2000 by the RMP. The analysis of the fish from 2000 is not complete. Given only two years of results, indications of increasing or decreasing fish contamination are tentative. Concentrations of several contaminants including PCBs, chlordane, dieldrin, and DDT were lower in 1997 than in 1994. Results from studies in the 1970s and the state Toxic Substances Monitoring Program in the 1980s are sparse but suggest mercury levels in fish in the Bay are generally remaining stable.

Using the RMP to help manage the Estuary

Karen Taberski, Senior Environmental Specialist, Regional Water Quality Control Board

Until the 1990s our understanding of contaminants in the San Francisco Estuary was insufficient for the Regional Water Quality Control Board (Regional Board) to make informed decisions on complex issues. Prior to that time we didn't know the answer to basic questions such as: "Are water quality guidelines being met in the Estuary?" Since the inception of the RMP pilot in 1989 and the full RMP in 1993, the ability of the Regional Board to determine if water quality guidelines are being met, and if the beneficial uses of the Estuary are being protected, has greatly increased. The RMP has helped determine if toxic water may be impairing aquatic life and if Estuary fish are safe to eat. Studies of contamination in the sediment, from the air, and at river mouths have allowed us to begin to understand the sources of contamination to the Estuary. This information has been used by the Regional Board in developing the 303(d) list of impaired water bodies (see *The Clean Water Act and TMDLs,* page 12) and in issuing water quality permits. In 1998, RMP data were used to refine the Estuary's 303(d) contaminant list from all metals to only copper, nickel and mercury. The RMP will continue to be instrumental in the TMDL process.

"The RMP is being specifically redesigned to provide data, in a rigorous scientific manner, that the Regional Board thinks are necessary to address urgent regulatory issues."

The Regional Board feels that the RMP has provided one of the most complete pictures of contaminants in any estuary in the United States. Nevertheless, large data gaps remain. For instance, more information is needed on where contaminants come from (sources), how contaminants enter the Estuary (pathways) and the amount of contaminants that enter the Estuary (loadings). This information is critical to the development of meaningful TMDLs. The effects of contaminants also need to be better understood to determine if the Estuary's beneficial uses are being protected.

In 1998, after a review of the RMP by outside experts, a redesign of the program was begun in order to increase its value to Estuary managers. Recommendations on how to fill data gaps were developed, and redesign actions were prioritized by the Regional Board and RMP participants based on management needs. New projects will be phased in to minimize sudden budget increases. During priority setting, staff considered all other research and monitoring programs in the Estuary in order to benefit from the work of other programs, avoid redundancy, and maximize efficiency. Therefore, the RMP is being specifically redesigned to provide data, in a rigorous scientific manner, that the Regional Board thinks are necessary to address urgent regulatory issues.

A key feature of the redesign is the development of contaminant budgets (see *Analyzing contaminant movement and storage* on page 23.). In addition to budgets, studies are planned to specifically assist the Regional Board in making management decisions. A study to evaluate sediment contamination on a local scale will assist decisions on sediment cleanups at military and other sites. Contaminant effects indicators will be developed (see *Improving contaminant effects monitoring*, page 25) to help the Regional Board determine if aquatic life is being protected. Information will be gathered on new chemicals of concern including flame retardants, pharmaceuticals and pesticides to determine if they have been detected in samples in the Estuary, have the potential to impair organisms, and should be measured on a regular basis (see *Unidentified contaminants*, next page). From this information the Regional Board can determine if management or regulation of these chemicals is warranted.

The Regional Board also made recommendations regarding status and trends measurements. Method improvements would allow the Regional Board to better interpret results, determine if standards are being met, and if not, help determine why. Changes to the status and trends portion of the RMP are being designed so the data collected will be appropriate to meet the requirements of the Clean Water Act. In addition, the monitoring of trends is being refined to better evaluate when changes in contaminant concentrations based on management efforts could be expected, and if these changes actually take place.

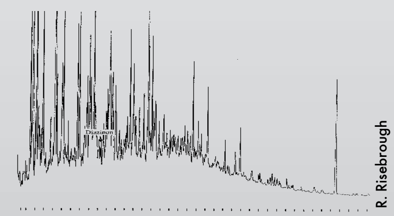
Changes to the RMP will continue to occur as future priorities develop, priorities based on sound science and a holistic understanding of the Estuary system.

UNIDENTIFIED CONTAMINANTS: HIDDEN THREAT?

DON YEE, ENVIRONMENTAL SCIENTIST, SAN FRANCISCO ESTUARY INSTITUTE

"The contaminants currently monitored by the RMP constitute only a small fraction of those present in the Estuary."

Contaminants currently monitored by the RMP constitute only a small fraction of those that are present in the Estuary and can be measured by current sampling and analysis methods. Immediate priorities have prevented effort from being spent on the rest, which are rarely mentioned even in the laboratory reports. Many of the monitored contaminants were chosen because they were designated priority pollutants by the U.S. Environmental Protection Agency after demonstrating adverse effects on humans or the environment. Monitoring focused on priority pollutants may fail to notice problems related to new emerging chemicals or older pollutants once thought benign. Cleaning up pollution problems after they are manifested is usually extremely difficult and expensive. Estuary monitoring should be more proactive and monitor a wide range of suspect chemicals so that problems are caught early and potentially devastating pollution is prevented.



This is the output of a lab instrument that analyzed an Estuary water sample. Each spike, small or large, indicates the presence of a different chemical compound. One was identified as the pesticide diazinon. The vast majority remained unidentified.

In the 1960s, a group of compounds were routinely detected in fish from the Estuary, but remained unidentified and unreported. These compounds were found to be toxic PCBs. Now banned, PCBs comprise one of the most intractable pollution problems in the Bay, likely to remain at levels of concern for human and ecological health for many years to come. Might a similar scenario be repeating itself today?

More recently, the widely used organophosphate insecticides diazinon and chlorpyrifos were identified after previously appearing as unknown compounds in environmental samples. Analysis instruments are now detecting signals of the pyrethroid pesticides, which are increasing in popularity and use. Although these compounds are particularly toxic by design, they are not as resistant to degradation as PCBs and the organochlorine pesticides of the past (such as DDT) and may represent a shorter-term threat. However, some other unknown compounds, if not carefully monitored and appropriately managed, could become the legacy pollutants of the future.

One such class of compounds may be the polybrominated diphenyl ethers (PBDEs). Widely used as fire retardants, they have recently been identified in samples of water and wildlife from the Estuary. Previously, they had been "unknown" compounds, detected but not identified. By reviewing raw analysis results (gas chromatograms and mass spectra) from Estuary samples analyzed over the past decade, the RMP aims to measure the environmental distribution of PBDEs, pesticides, and other previously unidentified organic compounds. This information, combined with data on toxicity, could then be used in a preliminary assessment of any need to manage the use of such compounds.

Methods such as gas chromatography and mass spectrometry (GC/MS) can capture a picture of the environment in a particular time and place, much like a surveillance camera might capture an image of the people passing through a hotel lobby. Some compounds might be always present and easily recognizable, while a large number of others might remain unidentified. A majority of these unidentified compounds may in fact be innocuous, much like the vast majority of hotel visitors who have legitimate business to conduct, but there may be a few "bad actors" within the crowd.

The RMP is planning a search for "bad actors" in the Estuary. The project will begin by combing the recent scientific literature to make sure our list of the usual suspects includes compounds which have only recently arrived or been suspected of causing environmental or human health impacts. By acquiring profiles of these compounds, such as the police do with mug shots of suspects, we may recognize them in past surveillance records. The historical data can show us changes in the quantity and distribution of these compounds in the Estuary. Combining these data with information on toxicity, we can determine where they might have an impact. Early recognition of potential impacts can incite us to act now to control the entry of these pollutants into the ecosystem and minimize the damage they may cause.

A second potential use of the historical data has a less certain outcome, akin to doing detective work from surveillance photos. By comparing images from different hotel lobbies following robberies, the police might recognize a person common to each. Similarly, we could correlate the presence of certain previously unknown compounds to the occurrence of environmental impacts at various sites. Such a case would be entirely circumstantial, but it could serve to provoke further investigative work, first to get more positive identifications of those compounds, and then to see if they really cause the impacts that we suspect.

Although there is often a tendency toward inaction unless the causes of environmental effects become incontrovertible, taking these proactive steps can help us avoid repeating the mistakes of the past. As the experience with PCBs has shown, human influence on the environment can be so rapid and of such a magnitude that by the time there is certainty about the impact, it may be too late to easily reverse the process. By monitoring for potentially toxic compounds prior to their becoming apparent problems, we can manage their use more appropriately, and thus prevent these pollutants from becoming the intractable and costly "legacy pollutants" of the future.

This article based upon a proposal by Robert Risebrough

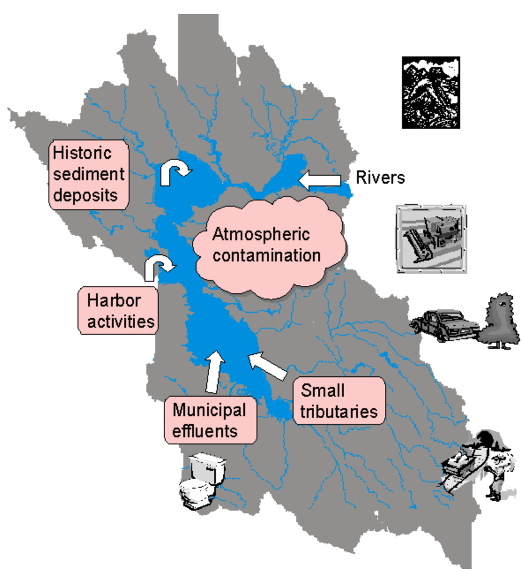


Figure 1. Illustration of sources, pathways, and loadings (inputs) of contaminants to the Estuary. Sources (gold and mercury mining, agriculture, industry, automobiles, municipal wastewater) are shown as pictures. Pathways (rivers, small tributaries, historic sediment deposits, harbor activities, air deposition) are shown as text. Loadings are indicated by arrows.

TRACKING DOWN CONTAMINANT SOURCES

JAY DAVIS, ENVIRONMENTAL SCIENTIST, SAN FRANCISCO ESTUARY INSTITUTE

Until recently, the RMP focused on describing general conditions in the Estuary. Sampling mainly took place in the middle of the Bay, far removed from contaminant inputs, and on a fixed schedule, without regard to rainstorms that can mobilize contaminants from the watershed. After seven years of sampling in this manner, the RMP has a good understanding of general ambient conditions in the Estuary. However, such sampling has yielded little information on where the contamination is coming from or whether contaminant loads to the Bay are increasing or decreasing. If management actions have reduced contaminant inputs to the Bay, it might take decades of sampling with the old approach to detect the reductions.

Now, the RMP is changing to more explicitly couple with efforts to identify, eliminate, and prevent sources of pollution, while maintaining long-term trend monitoring. Sampling locations will be added to include places representative of the major pathways for contaminant entry into the Bay. Rainfall-related contamination pulses, a key input to the Estuary, will be more fully characterized. If management actions succeed in reducing inputs, the RMP will be prepared to detect the reductions.

Modifications to the RMP will be assisted by the Sources, Pathways and Loading Workgroup, a collection of local experts with extensive experience in the input and cycling of contaminants in the Estuary. Developing an optimal design of RMP components to characterize sources will require an iterative process that takes new information into account. It is envisioned that the Workgroup will continue to help guide the RMP as changes proceed over the next several years.

A new report contains the current recommendations of the Workgroup; the technical background for those recommendations; summaries of the state of knowledge regarding Estuary-wide contaminant budgets, sources and pathways (see *Source vs. Pathway,* page 9); and priorities for changes to the RMP (Davis *et al.* 2001). The Workgroup agreed that information was needed on both sources and pathways, since there is concern both with describing the inputs to the Bay and determining how those inputs can be reduced.

	Historic Sediment	Creeks & Drains	Direct Air Dep	Rivers	Waste-Water	Harbor Activities
PCBs	●	○	○	○		
PAHs	●	○	○	○		
Registered pesticides		○	○	●	○	
Mercury	●	○	○	●		
Selenium				●	●	
Copper	●	○		○		○
Nickel	●	○		●		
Silver	●			●		
Cadmium		○		○		

Figure 2. Current understanding of the significance of inputs from each major contaminant pathway. Shaded symbols indicate input is significant. Unshaded symbols indicate input is possibly or probably significant. Where no symbol is shown input is minor or probably minor.

The report identified six primary pathways for contaminant entry into the Estuary: historic sediment deposits in the Estuary, creeks and storm drains, deposition from the air, the Sacramento and San Joaquin Rivers, wastewater discharges, and harbor activities including dredging. A summary of current understanding of the size of each of these pathways is presented in Figure 2. Existing information indicates that historic sediment deposits are a significant pathway for some contaminants. Creeks and storm drains may be a significant pathway for many contaminants, but reliable estimates of the magnitude of this pathway are lacking. Air deposition may be significant for PCBs, PAHs, and mercury. The RMP Atmospheric Deposition Pilot Study is providing valuable information in this regard. The Sacramento and San Joaquin Rivers, which drain an expansive watershed with intensive historic and current mining, agriculture, industry, and hydroelectric development, are considered to be a significant pathway for registered pesticides, mercury, selenium, nickel, and silver, and may be a significant pathway for PCBs, PAHs, copper, and cadmium. Wastewater discharges are a significant pathway for selenium, and probably a significant pathway for some pesticides. Harbor activities may be a significant pathway for copper.

As a first step, the Workgroup recommended further review of existing information, including contaminant transport from the Sacramento and San Joaquin rivers during high flows, sources of PAHs, contamination at creek mouths, selenium geology and relation to land use in the South Bay, urban and agricultural uses of pesticides, and resuspension of bottom sediments.

This year the RMP will prepare a second report presenting the findings of this review and also draft a long-range (e.g. 5 year) plan outlining the changes needed to best support efforts to identify, eliminate, and prevent sources of pollution to the Estuary.

Analyzing contaminant movement and storage

Jay Davis, Environmental Scientist, San Francisco Estuary Institute

In 1997 a panel of national experts on monitoring recommended that the RMP develop budgets of contaminant movement and storage among the water, sediment, air and organisms of the Estuary. These budgets (known as “mass budget models” to researchers) typically take the form of a box-and-arrow diagram and corresponding set of equations. Such budgets are of great value in summarizing the existing state of knowledge, synthesizing information from the RMP and other programs on contaminants in the Bay, predicting changes in contaminant concentrations in the Bay due to management actions and natural processes, identifying data gaps, and communicating RMP results (SFEI 1998). More recently, the initiation of TMDLs (see *The Clean Water Act and TMDLs,* page 12) by the Regional Board and EPA has placed additional emphasis on the need for budgets.

Using RMP data and other information, budgets for all high-priority contaminants are being developed. A preliminary PCB budget is already complete (Figure 1). Currently, the RMP and Regional Board are collaborating to develop and refine a food web section of the budget (Figure 2).

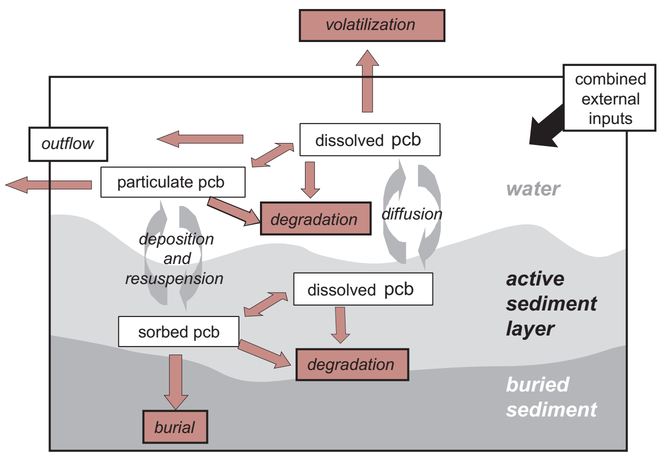


Figure 1. Preliminary PCBs budget.

The PCB budget treats the whole Estuary as one box with two compartments: water and sediment (Figure 1). Five major processes that result in addition or removal of PCBs from water or sediment are included: external inputs, outflow to the ocean, volatilization (evaporation) to the atmosphere, burial in deep sediment, and degradation by microbes or chemical processes. Also included are transfers of PCBs between water and sediment: diffusion of dissolved PCBs and deposition and resuspension of PCBs bound to sediment particles. The budget can be used to predict the changes in average PCB concentrations in water and sediment over time.

A great deal of information about the Bay is needed to develop the budget. Data on physical features of the Bay are needed, such as water volume, the volume of active sediment, the concentration of particles in water and sediment, and others. Needed to estimate volatilization are water temperature and wind speed data. Rates of particle and water exchange between water and sediment must be estimated. Bay-wide average concentrations of PCBs in water and sediment are needed, as are data on the chemical properties of PCBs. Sources of these data include the RMP, several U.S. Geological Survey research and monitoring efforts, the Department of Water Resources, the Long Term Management Strategy [for dredging], the National Weather Service, and other budgeting efforts described in the scientific literature. As foreseen by the Review Panel, the PCB budget has been very useful in summarizing the existing state of knowledge and providing a framework for synthesizing information from the RMP and other programs on contaminants in the Bay.

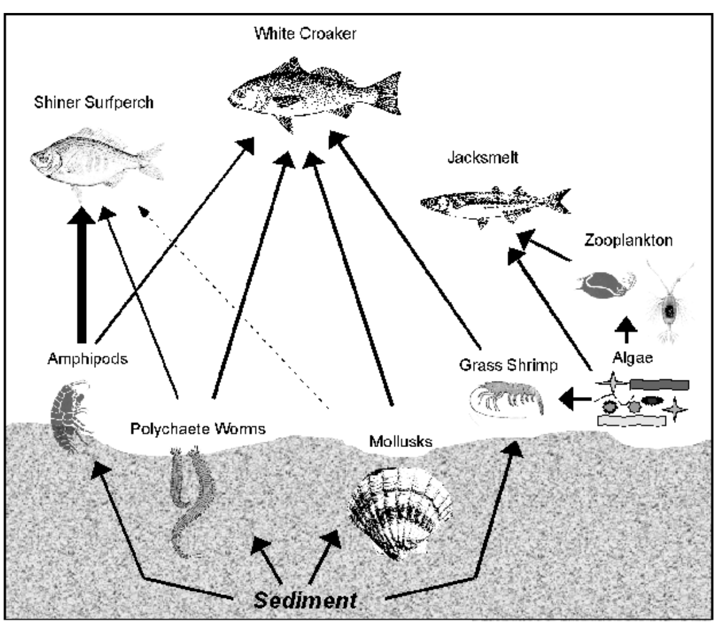


Figure 2. Diagram of food web budget.

The key output of the PCB budget is a predicted rate of decline of PCBs under different management scenarios. These predicted rates of decline can be matched to past data in an attempt to use the budget to better understand our current situation, or they can be used to forecast trends into the future. Based on the observed rate of PCB decline from 1982–1998, it appears that PCBs inputs to the Bay during this period were approximately 25 kilograms (55 pounds) per year. This value is also consistent with other information on PCB distribution in the watershed.

Looking into the future, if inputs of 25 kg/yr continue, in 10 years the overall quantity of PCBs in the Estuary (excluding buried PCBs, which here are considered removed from the Estuary) would be expected to fall by 29%. During this 10 year period, the 250 kg entering the Estuary would be offset by 385 kg lost via volatilization, outflow to the ocean, burial in deep sediments, and degradation (Figure 3). The budget can also be used to evaluate other scenarios. If the inputs of PCBs could be reduced to 10 kg/yr, the overall loss from the Bay in a 10 year period is predicted to be 49%. If inputs could be eliminated entirely, a decline of 62% over a 10 year period is predicted. It should be noted that many of the parameters for the budget are difficult to estimate, and consequently there is a large amount of uncertainty associated with the budget results. One of the valuable functions of the budget, however, is to pinpoint the data that are most critical to predicting future trends.

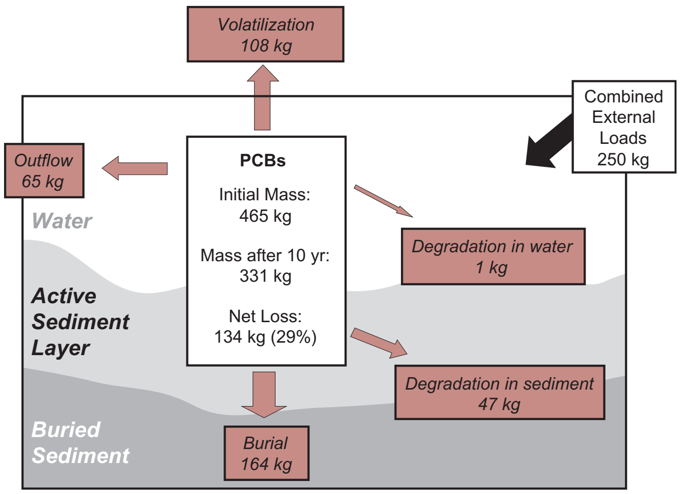


Figure 3. Ten-year PCBs budget with 25 kilograms per year input.

The PCB budget is the RMP's first experience with development of a contaminant budget. This budget has proven to be useful in all of the ways envisioned by the Review Panel. Other budgets to be developed, or adapted from the work of others, will cover PAHs, mercury, copper, nickel, and selenium. In the next few years, contaminant budgets will become a cornerstone of the RMP.

Improving contaminant effects monitoring

Bruce Thompson, Senior Scientist, San Francisco Estuary Institute

Understanding the effects of contamination on the organisms that inhabit the Estuary is at the heart of environmental protection. Water quality guidelines are set based on knowledge of contaminant effects, and toxicity tests and standards are intended to detect potential contaminant effects and keep actual effects from occurring.

Why then, has the RMP not included more monitoring for contaminant effects? The short answer is that the identification of reliable indicators of contaminant effects is a complex task, and interpretation of the results is often difficult. The generally moderate levels of contamination in the Estuary may be producing effects that are difficult to distinguish from those caused by other environmental factors such as changes in salinity, sediment type, life stage variations, non-native species abundance, and freshwater diversions.

The RMP does conduct some limited effects monitoring. Aquatic and sediment toxicity has been monitored since 1993 (see *Toxicity testing*, page 13). However these are laboratory tests that use organisms that may not inhabit the Estuary. Therefore, any indications of toxicity from those tests are considered to indicate the *potential* for effects in the Estuary. The RMP monitored benthos (organisms that live in bottom sediments) in an attempt to evaluate effects of sediment contamination. But after four years and the collection of almost 600 samples, it was difficult to clearly attribute changes in the benthos to sediment contamination (Thompson and Lowe 2000). The RMP also monitors the level of contaminants in fish and shellfish tissues. Tissue contamination is not an adverse effect *per se*, but it may lead to an effect. The RMP's limited work to monitor effects has not conclusively linked contamination with any biological effects in the Estuary, although there is some strong evidence (Thompson *et al.* 1999; Ogle *et al.* 2000, Thompson and Lowe 2000). However, other studies in the Estuary have made such links (Hornberger *et al.* 2000; Brown and Luoma 1999).

"Considering the numerous kinds of contaminants, varying sensitivities of organisms, different types of contaminant effects, and problems with interpretation, it should not be surprising that the RMP has been slow to adopt biological effects measurements."

There are many variables involved with contaminant effects. Different organisms in the same environment can be exposed differently. For example, a clam may actually "clam-up" when exposed to contaminated water and receive a lower dose than a soft-bodied, free-living organism. Some organisms are more sensitive to contaminants than others. Generally, organisms lower in the food web, such as shrimp, are more sensitive than organisms higher in the food web, such as fish.

Each contaminant has a different mode of toxicity. Contaminants can affect the nervous system (organophosphate pesticides, mercury, PCBs), the reproductive system (metals, PCBs), the development of embryos (selenium, mercury, PCBs), metabolism (metals), etc. The observed effects could include death, decreased growth, or reproductive impairment. If persistent and severe enough, these problems may be observed as population reductions or altered communities.

Thus, contaminant effects may be measured at several levels of biological organization: the cellular, tissue, organ, or organism level, as well as at the population or community levels. Cellular or tissue level effects determined in controlled, laboratory settings may provide the most direct evidence of effects, but leave questions of biological relevance in the Estuary, especially whether organism populations are affected. However, early warnings about contaminant effects, before populations are affected, are desirable. Therefore, using effects indicators at several levels of biological organization is commonly advised. But which levels are best, and what specific indicators should be selected?

Even when effects measurements are successfully made, interpretations of those measurements may be difficult, mainly because apparent effects of contamination are often confounded by influences of other factors. For example, the nutrition or reproductive condition of an organism may influence or be mistaken for a contaminant effect. Similarly, changes in salinity, life history, predation or competition may confound understanding effects on populations or communities. The identification of appropriate effects indicators requires understanding the role of confounding factors. That understanding only comes from a great deal of study of the organism or the ecosystem where its response to contamination and a full range of environmental factors can be observed.

Considering the numerous kinds of contaminants, varying sensitivities of organisms, different types of effects, and problems with interpretation, it should not be surprising that the RMP has been slow to adopt effects measurements. Despite these difficulties, it is essential for the RMP to commit to measuring contaminant effects. Good indicators must be carefully selected, then monitored long-term throughout the Estuary. Effects indicators are an active area of research, and much may be gleaned from other studies. Results from multiple indicators can be interpreted using a weight-of-evidence approach.

In 2001, a group of experts on contaminant effects will help identify studies needed to select a set of indicators of contaminant effects for use in the RMP. It is anticipated that those indicators identified will be tested in pilot studies over the next few years before selecting a subset that have been shown to reliably indicate the occurrence of contaminant exposure and effects.

Fitting the RMP into the monitoring milieu

Rainer Hoenicke, RMP Manager, San Francisco Estuary Institute

What do Propositions 204 (establishing the CALFED partnership to "fix the Delta"), 12 and 13, big State budget surpluses, and the sudden prominence of Section 303(d) of the Clean Water Act have in common? The answer is: they all play a role in an unprecedented influx of resources into environmental monitoring and restoration. Those resources now support an array of activities including habitat inventories, investigations into the causes of species declines, and studies of contaminant sources and effects.

Prior to 1996, the RMP was one of the largest and best-funded monitoring efforts in the Bay Area, but since then, the resources made available to other programs have dwarfed the RMP's $3 million annual budget. This represents both an opportunity and a challenge. An opportunity, because filling data gaps is the first step toward making better environmental management decisions and improving degraded ecosystem conditions. A challenge, because it is more difficult to keep track of various efforts and combine them into meaningful, coordinated work without wasting resources. The RMP Steering Committee has not only recognized this, it has challenged both the Regional Board and the SFEI to work toward integrating RMP activities with the work of CALFED and numerous others studying one of the most complex ecosystems in the world.

SFEI anticipated this in 1999 when it formed the Contaminant Monitoring and Research Program and generated enough funding from sources other than the RMP to help coordinate, keep track of, and integrate data from many disparate information sources. SFEI has been fairly successful in avoiding duplication of effort and leveraging funds from federal and state agencies. The RMP's development of conceptual contaminant budgets (see *Analyzing contaminant movement and storage,* page 23) also helped identify data gaps and focused RMP priorities into areas that were not yet addressed by other programs. The collaborative structure of the RMP also promotes interactions between scientists that traditionally have not found a need to conduct interdisciplinary team research and share ideas. Furthermore, RMP Pilot Studies are frequently enticing outside agencies to participate, or start their own complementary projects, such as was the case with the Seafood Consumption Study and the recently begun effort by the Environmental Protection Agency, the California Air Resources Board and other partners to monitor dioxins in air.

The RMP must stay informed of new monitoring efforts, and continue to look for collaborators, to ensure our knowledge of the Estuary is as extensive as possible and each monitoring dollar is put to best use.

"The RMP must stay informed of new monitoring efforts, and look for collaborators, to ensure our knowledge of the Estuary is extensive and each monitoring dollar is put to best use."

RMP TECHNICAL REPORTS

RMP technical reports offer a detailed look at Estuary contamination topics, and provide a way to learn more about some of the information contained in The Pulse. This list includes all technical reports in preparation or produced since the last RMP Annual Report. Reports are organized by topic. Some reports are published journal articles and are noted as such. If a report is available on the web, a web address (URL) is provided. Hard copies of each report are available for purchase from the San Francisco Estuary Institute (510) 231-9539, unless otherwise noted.

Benthos

Results of the Benthic Pilot Study, 1994–1997
I: Macrobenthic Assemblages of the San Francisco Bay-Delta
Published: August 2000
Authors: Bruce Thompson, Sarah Lowe, and Michael Kellogg
The purpose of the first chapter of the Benthic Pilot Study report is to provide a foundation for the development of benthic indicators of impacted conditions. This report describes the species composition, abundances, and distribution of the benthic assemblages in the San Francisco Bay and Delta, defines the ranges of abiotic variables for each assemblage, and identifies the abiotic factors that have the most influence on the assemblages and their variation.
URL: http://www.sfei.org/rmp/reports/benthicpilot/94-97_benthic.pdf

Results of the Benthic Pilot Study, 1994–1997—Draft Report
II: A Preliminary Assessment of Benthic Responses to Sediment Contamination in San Francisco Bay.
Target Availability: 2001
Authors: Bruce Thompson and Sarah Lowe.
The objectives of the second chapter of the Benthic Pilot Study report are to identify benthic indicators of contaminated sediments in the Bay, determine background or reference benthic conditions for the Bay's major benthic assemblages, and develop a benthic assessment procedure to determine the degree of impact by contamination.

Bioaccumulation
The Challenges of Bivalve Bioaccumulation Monitoring in a Highly Variable Environment—Draft Report
Target Availability: April 2001
Authors: Dane Hardin, Rainer Hoenicke, Andrew Gunther, David Bell, and Jordan Gold
Bivalve bioaccumulation monitoring has been widely used to estimate bioavailable contaminants, to assess the relative differences in the degree of contamination, and to provide an estimate of the ecological effects of contamination. This report analyzes RMP bioaccumulation data from 1993–1998 to determine whether variation in non-contaminant water-quality parameters (salinity, temperature, and the concentrations of dissolved oxygen, suspended particulate matter, and chlorophyll) could affect levels of bioaccumulation and indicators of health in bivalves deployed in the Estuary.
URL: http://www.sfei.org/rmp/reports/bivalvemonitoring/bivalve_93-98.html

Estuary Contamination, General

San Francisco Bay Episodic Toxicity Report: 1999 Progress Report
Published: October 2000
Authors: R. Scott Ogle and Andrew J. Gunther
Ambient water samples are collected as part of the RMP's baseline monitoring and are evaluated using the short-term chronic *Mysidopsis bahia* testing approach, with survival as the test endpoint. Occurrences of significant toxicity throughout the northern San Francisco Bay system were observed following major storm events during the winter of 1996–97. Since the toxic water samples were collected immediately following major rainstorms, this suggests that ambient water toxicity in San Francisco Bay can occur over short time scales, e.g. the result of stormwater runoff and/or other surface water runoff events. In response to these observations, a Special Study was initiated by the RMP to investigate possible episodic toxicity in the San Francisco Bay. Beginning in the winter of 1996–97, toxicity tests have been performed on ambient water samples from stormwater runoff entering the Bay at selected sites. This Progress Report discusses the performance and results from three sampling years of episodic toxicity monitoring.
URL: *http://www.sfei.org/rmp/reports/episodic_toxicity/epis_tox_1999.html*

A PCB Budget for San Francisco Bay—Draft Report
Target Availability: March 2001
Author: Jay A. Davis
A mass budget for PCBs was developed in order to evaluate the likelihood of continuing inputs of PCBs to the Bay and to understand the response time of the Bay for PCBs. The modeling approach described here is a simple, first step toward a quantitative understanding of the long-term fate of PCBs in the Bay. The model allows evaluation of the long-term response of the Bay to varying PCB loads, providing information that is valuable in understanding the potential impact of cleanup efforts.
URL: http://www.sfei.org/rmp/reports/pcb/pcbmodel.pdf

Episodic Ambient Water Toxicity in the San Francisco Estuary
Target Availability: April 2001
Authors: R. Scott Ogle, Andrew J. Gunther, David Bell, Jeffrey Cotsifas, Jordan Gold, Paul Salop, and Rainer Hoenicke
The purpose of this RMP Special Study is to begin documenting the frequency and duration of episodic toxicity events in the San Francisco Estuary. This report summarizes and reviews toxicity testing results of ambient water samples collected following significant rainstorm events and high frequency sampling at a location influenced by agricultural discharges during 1996-2000. Episodes of ambient water toxicity to *Mysidopsis bahia* have been documented that probably would not have been detected using traditional periodic ambient water sampling designs. Results of ELISA analyses suggest that some of this toxicity may be due to organophosphate pesticides in runoff, while the causes of most of the observed ambient water toxicity remains unknown. Results also suggest that changes in the types of ambient toxicity in the Estuary may be occurring. Therefore, it is critical that monitoring programs such as this one adapt their monitoring approach to reflect changes in activities within the monitoring area watersheds.
URL: http://www.sfei.org/rmp/reports/episodic_toxicity/epis_tox_2000.pdf

San Francisco Bay Seafood Consumption Study, Technical Report
Target Availability: March 2001
Authors: SFEI, Environmental Health Investigations Branch, California Department of Health Services, Impact Assessment, Incorporated
The purpose of this study is to gather quantitative data that can be used to characterize the consumption of Bay-caught fish by the general fishing population of San Francisco Bay. Further goals of the study are to (1) identify people who may be highly exposed to chemicals from consuming Bay fish, and (2) to gather information needed to develop educational messages.
URL: http://www.sfei.org/rmp/reports/sfc_report/sfc_tr.pdf

San Francisco Bay Seafood Consumption Study, Public Summary
Target Availability: March 2001
Authors: SFEI, Environmental Health Investigations Branch, California Department of Health Services, Impact Assessment, Incorporated
A presentation of the results of the San Francisco Bay Seafood consumption Study for a general audience.
URL: http://www.sfei.org/rmp/reports/sfc_report/sfc_publicsummary.pdf

Sediment

Investigation of Chemicals Associated With Amphipod Mortalities at Two Regional Monitoring Program Stations
Target Availability: April 2001
Authors: Brian Anderson, John Hunt, Bryn Phillips, and Jose Sericano
Seasonal variable mortality of amphipods has been observed at a number of RMP stations, particularly those in the South Bay and in the northern Estuary. Amphipod mortality is measured in whole sediment samples using the estuarine amphipod, *Eohaustorius estuarius*. This report discusses results of preliminary experiments designed to investigate chemicals responsible for the mortality of amphipods at the Redwood Creek and Grizzly Bay RMP stations.
URL: http://www.sfei.org/rmp/reports/amphipod/amphipod.pdf

Investigations of Sediment Elutriate Toxicity at Three Estuarine Stations in the San Francisco Bay, California
Available: April 2001
Authors: Bryn M. Phillips, Brian S. Anderson and John W. Hunt
Since sampling began in 1993, significant toxicity to bivalves has been detected in all but one of the sediment elutriate samples from the Grizzly Bay, Sacramento River, and San Joaquin River RMP stations. As part of a Special Study, investigations to characterize the potential causes of toxicity began with Phase I Toxicity Identification Evaluations (TIEs) and chemical analyses. As more information was discovered and new questions identified, the investigative strategy was altered to include TIE manipulations at the sediment-water interface, additional elutriate exposures in a freshwater matrix, and a novel approach for determining the cupric ion concentration in the samples. This report analyzes

and interprets the 1998 sediment elutriate results for the three stations.
URL: http://www.sfei.org/rmp/reports/ties/ties_98.pdf

Sources, Pathways and Loadings

Estuary Interface Pilot Study, 1998 Progress Report
Published: October 2000
Authors: Jon Leatherbarrow and Rainer Hoenicke
Initial RMP monitoring results suggested that the Estuary margins generally exhibited higher concentrations of trace elements and trace organic pollutants in water and sediment than those of deeper parts of the Bay. The objective of this Pilot Study is to determine the contribution of pollutants to the Estuary from sources in adjacent watersheds. This Progress Report describes 1998 sampling results from the study's two stations located at the upper end of the tidal prism of Coyote Creek and at the mouth of the Guadalupe River.
URL: http://www.sfei.org/rmp/reports/eipprogressreport/eip98.html

Results of the Estuary Interface Pilot Study, 1996-1999
Target Availability: May 2001
Authors: Jon Leatherbarrow, Rainer Hoenicke, and Lester McKee
The purpose of the Estuary Interface Pilot Study is to determine the potential contribution of contaminants from watershed sources to the receiving waters in the San Francisco Bay. Beginning in 1996, the RMP has monitored water and sediment at two stations located at the estuary-watershed interface, in the Coyote Creek and at the mouth of the Guadalupe River. This report summarizes the results from four years of monitoring at the Estuary Interface, compares pollutant profiles between watersheds and the Estuary, and provides recommendations for improving sampling design and methodology for characterizing contaminant loads from watershed sources.
URL: http://www.sfei.org/rmp/reports/eip_study/eip_summary.html

San Francisco Bay Atmospheric Pilot Study [Three Part Report]
Deposition of pollutants from the atmosphere to surface water can occur by several processes, including rain or snow-scavenging of gases and particles, dry deposition of dust particles, deposition through cloud and fog water, and air-water exchange processes.
The primary objectives of this Pilot Study include estimating annual atmospheric loading of selected pollutants to the San Francisco Estuary and comparing atmospheric loading with loading from other sources and pathways.

Part 1 – Mercury—Draft
Target Availability: March 2001
Authors: Pam Tsai and Rainer Hoenicke
This report presents study methodology, concentrations of mercury detected in the ambient air and precipitation, estimated deposition loads to the San Francisco Estuary, and comparison of loadings from different primary sources and pathways.
URL: http://www.sfei.org/rmp/reports/air_dep/airdep_prt1.html

Part 2 – Trace Metals
Target Availability: April 2001
Authors: Pam Tsai, Rainer Hoenicke, and others
This report will present study methodology, concentrations of trace metals (Cu, Ni, Cd, and Cr) detected in the precipitation, deposition rate of trace metals that are entrapped in particulate matter, and estimated deposition loads to the San Francisco Estuary. Comparison of loading from atmospheric deposition with that from other primary sources and pathways will also be evaluated.
URL: http://www.sfei.org/rmp/reports/air_dep/airdep_prt2.html

Part 3 – Trace Organics
Target Availability: June 2001
Authors: Pam Tsai, Rainer Hoenicke, and others
This report will present study methodology, concentrations of PAHs and PCBs detected in the ambient air, and estimated deposition loads to the San Francisco Estuary.

URL: http://www.sfei.org/rmp/reports/air_dep/airdep_prt3.html

Part 3.1- Trace Organics—Laboratory Report
Published: February 5, 2001
Authors: Joel Baker and Holly Bamford
This report presents sampling and analytical methodology, and concentrations of PAHs and PCBs detected in ambient air samples collected at the Concord Site. Trace organics in vapor phase and particulate phase were collected and analyzed separately.
URL: http://www.sfei.org/rmp/reports/air_dep/airdep_prt3_1.html

Technical Report of the Sources, Pathways, and Loadings Workgroup, September 1999
Published: February 2001
Authors: Jay A. Davis, Khalil Abu Saba, and Andrew J. Gunther
This report presents contaminant summaries of the state of knowledge regarding overall mass budgets for the Bay and the magnitude of loading from individual sources and pathways to the Bay. In addition to producing recommendations pertaining to sources, pathways, and loading of the priority contaminants, the workgroup also provides more general recommendations for modifying trace metal monitoring in the RMP to better meet the program's objectives.
URL: http://www.sfei.org/rmp/reports/splwg/splwg_sep99.pdf

Water

Summary of Suspended-Solids Concentration Data, San Francisco Bay, California, Water Year 1999
Published: 2000
Authors: Paul A. Buchanan and Catherine A. Ruhl, U.S. Geological Survey (USGS).
This report summarizes the suspended-solids concentration data collected during water year 1999 (October 1, 1998 to September 30, 1999). Water samples were collected periodically at sites in Suisun Bay, San Pablo Bay, Central San Francisco Bay, and South San Francisco Bay and analyzed for concentrations of suspended solids. This report is the latest in a series that summarizes suspended-solids concentration data collected in the San Francisco Bay beginning in water year 1992. These data are used by the USGS to determine factors influencing suspended-solids concentrations in the San Francisco Bay.
Available from U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225.

RMP Related Studies

Contaminant Concentrations in Fish from the Sacramento–San Joaquin Delta and Lower San Joaquin River, 1998
Published: September 2000
Authors: J.A. Davis, M.D. May, G. Ichikawa, and D. Crane.
This report documents the most systematic, comprehensive survey of chemical contamination of fish in the Delta yet performed. This pilot study (1) examines whether mercury, organochlorine pesticides, and PCBs occur in fish are of potential concern to human health, (2) measures contaminant levels in fish to begin to track long-term trends, (3) attempts to determine spatial patterns in contamination in the Delta, (4) provides data to assess ecological hazards of mercury and organochlorines in organisms at high trophic levels. Sampling was carried out in late summer 1998 and focused on largemouth bass and white catfish.
URL: http://www.sfei.org/deltafish/dfc.pdf

Contaminant Loads from Stormwater to Coastal Waters in the San Francisco Bay Region: Comparison to other pathways and recommended approach for future evaluation
Published: 2000
Authors: Jay A. Davis, Lester J. McKee, Jon E. Leatherbarrow, and Ted H. Daum.
This report is the result of the California Legislature's Assembly Bill 1429, which mandates that action be taken to address gaps in knowledge of contaminant discharge to California's coastal waters. The Coastal Watershed Loading Project provides the framework for this collaborative effort by the San Francisco Estuary Institute, the Southern California Coastal Water Research Project, and the Moss Landing Marine Laboratories at California State University. The focus of this report is (1) to estimate the total discharge of pollutants from state coastal watersheds to bays, estuaries, and coastal waters from all sources, (2) to identify the relative contribution of stormwater to the total discharge of contaminants to coastal waters, (3) to describe methodologies for improved monitoring of the mass discharge of contaminants from stormwater, and (4) to estimate the costs of implementing a stormwater monitoring program and propose an implementation schedule.
URL: http://www.sfei.org/stormwater/ab1429.pdf

Sediment Contamination in San Leandro Bay, CA
Published: December 2000
Authors: Ted Daum, Sarah Lowe, Rob Toia, Greg Bartow, Rusell Fairey, Jack Anderson and Jennifer Jones
This study had five objectives: to evaluate the distribution of sediment contamination, to determine if the contamination was relatively isolated or not, to identify possible sources and pathways, to investigate the depth of sediment contamination, and to explore a method of sediment dating to see if it could be used to determine if the sediments are erosional or depositional within the embayment.
URL: http://www.sfei.org/sanleandrobay/finalslbay.pdf

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Photos used inside the report by David Bell and Michael May.

REFERENCES

Abu-Saba, K. and L.W. Tang. 2000. Watershed Management of Mercury in the San Francisco Bay Estuary: Total Maximum Daily Load Report to U.S. EPA. California Regional Water Quality Control Board, San Francisco Bay Region. Oakland CA. (http://www.swrcb.ca.gov/rwqcb2/Downloadable_Files/downloadable_files.html)

Anderson, B., J. Hunt, B. Phillips, J. Sericano. 2000. Investigation of chemicals associated with amphipod mortality at two Regional Monitoring Program stations. Draft Report. San Francisco Estuary Institute, Richmond, CA.

Brown, C.L., and S.N. Luoma. 1999. Metal trends and effects in Potamocorbula amurensis in north San Francisco Bay, *in* Morganwalp, D.W., and H.T. Buxton, eds., U.S. Geological Survey Toxic Substances Hydrology Program—Proceedings of the Technical Meeting, Charleston, South Carolina, March 8-12, 1999—Volume 2 of 3—Contamination of Hydrologic Systems and Related Ecosystems: U.S. Geological Survey Water-Resources Investigations Report 99-4018B, p. 17-21.

Cloern, J., B. Cole, J. Edmunds, T. Schraga, and A. Arnsberg. 1999. Patterns of water-quality variability in San Francisco Bay during the first six years of the RMP, 1993–1998. Prepared for the San Francisco Estuary Institute, Richmond, CA.

Collins, J. and M. May. 1997. Contamination of Tidal Wetlands. In 1996 Annual Report: San Francisco Estuary Regional Monitoring Program for Trace Substances. 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

Davis, J.A., D.M. Fry, and B.W. Wilson. 1997. Hepatic ethoxyresorufin-o-deethylase (EROD) activity and inducibility in wild populations of double-crested cormorants. Environmental Toxicology and Chemistry 16(7):1441-1449.

Davis, J.A.,M.D. May, G. Ichikawa, and D. Crane. 2000 Contaminant Concentrations in Fish from the Sacramento-San Joaquin Delta nad Lower San Joaquin River, 1998. San Francisco Estuary Institute, Richmond, CA

Deanovic, L., H. Bailey, T. Shed, and D. Hinton. 1996. Sacramento-San Joaquin Delta Bioassay Monitoring Report, 1993-1994. University of California, Davis, CA.

Deanovic, L., K. Cortwright, K. Larsen, E. Reyes, H. Bailey, and D. Hinton. 1998. Sacramento-San Joaquin Delta Bioassay Monitoring Report, 1994-1995: second annual report to the Central Valley Regional Water Quality Control Board. University of California, Davis, CA.

Flegal A.R., I. Rivera-Duarte, P.I. Ritson, G.M. Scelfo, G.J. Smith, M.R. Gordon, and S.A. Sanudo Wilhelmy. 1996. Metal contamination in San Francisco Bay waters: historic perturbations, contemporary concentrations, and future considerations. In Hollibaugh, J.T. (ed.), San Francisco Bay: The Ecosystem: further investigations into the natural history of San Francisco Bay and Delta with reference to the influence of man. pp. 173-188. Pacific Division, American Association for the Advancement of Science, San Francisco, CA.

Foe, C. 1995. Insecticide concentrations and invertebrate bioassay mortality in agricultural return water from the San Joaquin Basin. Staff Report. Central Valley Regional Water Quality Control Board, Sacramento, CA.

Foe, C. and V. Connor. 1991a. San Joaquin watershed bioassay results, 1988-90. Central Valley Regional Water Quality Control Board, Sacramento, CA.

Foe, C. and V. Connor. 1991b. 1989 Rice season toxicity monitoring results. Staff Report. Central Valley Regional Water Quality Control Board, Sacramento, CA.

Foe, C., L. Deanovic, and D. Hinton. 1998. Toxicity Identification Evaluations of orchard dormant spray storm runoff. California Regional Water Quality Control Board, Central Valley Region, Sacramento, CA.

Hornberger, M., S. Luoma, D. Cain, F. Parchaso, C. Brown, R. Bouse, C. Wellise, J. Thompson. 1999. Bioaccumulation of metals by the bivalve Macoma balthica at a site in South San Francisco Bay between 1977 and 1997: long-term trends and associated biological effects with changing pollutant loadings. U.S. Geological Survey Open File Report 99-55.

Johnson, G.W., W.M. Jarman, C.E. Bacon, J.A. Davis, R. Ehrlich, and R.W. Risebrough. 2000. Unmixing polychlorinated biphenyl source fingerprints in surface waters of San Francisco Bay. Environ. Sci. Technol. 34(4): 552-559.

Long, E.R., D.D. MacDonald, S.L. Smith, and F.D. Calder. 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Env. Mgmt. 19:81-97.

OEHHA. 1994. Health advisory on catching and eating fish: interim sport fish advisory for San Francisco Bay. Office of Environmental Health Hazard Assessment, California Environmental Protection Agency, Sacramento, CA.

Ogle, S., A. Gunther, and R. Hoenicke. 1998. Episodic toxicity in the San Francisco Bay system. Interagency Ecological Program Newsletter 11(2):14-17.

Phillips, B., B. Anderson, and J. Hunt. 2000. Investigations of sediment elutriate toxicity at three estuarine stations in San Francisco Bay. Draft Report. San Francisco Estuary Institute, Richmond, CA.

SFEI. 1998. Five-Year Program Review: Regional Monitoring Program for Trace Substances in the San Francisco Estuary. San Francisco Estuary Institute, Richmond, CA.

SFEI. 1999a. Contaminant concentrations in fish from San Francisco Bay, 1997. San Francisco Estuary Institute, Richmond, CA.

SFEI. 1999b. Regional Monitoring Program for Trace Substances. Report of the Pesticide Workgroup. San Francisco Estuary Institute, Richmond, CA.

SFEI. 1999c. Regional Monitoring Program for Trace Substances. Technical Report of the Chlorinated Hydrocarbon Workgroup. San Francisco Estuary Institute, Richmond, CA.

SFEI. 1999d. Regional Monitoring Program for Trace Substances. Technical Report of the Sources, Pathways, and Loadings Workgroup. San Francisco Estuary Institute, Richmond, CA.

SFEI. 2000. Management questions guiding the Regional Monitoring Program for Trace Substances—First Edition, 1998. San Francisco Estuary Institute, Richmond, CA. (http://www.sfei.org/rmp/documentation/management_q.html)

Spies, R.B. and D.W. Rice, Jr. 1988. The effects of organic contaminants on reproduction of starry flounder, Platichthys stellatus (Pallas) in San Francisco Bay. Part II. Reproductive success of fish captured in San Francisco Bay and spawned in the laboratory. Marine Biology 98:191-202.

Spies, R.B., D.W. Rice, Jr. and J.W. Felton. 1988. The effects of organic contaminants on reproduction of starry flounder, Platichthys stellatus (Pallas) in San Francisco Bay. Part I. Hepatic contamination and mixed-function oxidase (MFO) activity during the reproductive season. Marine Biology 98:181-189.S.R. Hansen & Associates. 1995. Identification and control of toxicity in storm water discharges to urban creeks. Prepared for Alameda County Urban Runoff Clean Water Program, Hayward, CA. Final Report, Including Appendices A & B, Volume I of VI.

Steding, D.J., C.E.Dunlap, and A.R. Flegal. 2000. New isotopic evidence for chronic lead contamination in the San Francisco Bay estuary system: Implications for the persistence of past industrial lead emissions in the biosphere. Proc. Natl. Acad. Sci. USA. 97(21):11181-11186.

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

Thompson, B.T. and S. Lowe. 2000. Results of the benthic pilot study, 1994–1997. Part II—A preliminary assessment of benthic responses to sediment contamination in San Francisco Bay. Draft report. San Francisco Estuary Institute, Richmond, CA.

Venkatesan, M.I., R.P. deLeon, A. van Geen, and S.N. Luoma. 1999. Chlorinated hydrocarbon pesticides and polychlorinated biphenyls in sediment cores from San Francisco Bay. Marine Chemistry 64:85-97.

Young, D, M. Becerra, D. Kopec, and S. Echols. 1998. GC-MS analysis of PCB congeners in blood of the harbor seal *Phoca vitulina* from San Francisco Bay. Chemosphere 37(4):711-733.

1999 RMP Program Participants

Municipal Dischargers:

City of Benicia
Burlingame Waste Water Treatment Plant
City of Calistoga
Central Contra Costa Sanitation District
Central Marin Sanitation Agency
Delta Diablo Sanitation District
East Bay Dischargers Authority
East Bay Municipal Utility District
Fairfield-Suisun Sewer District
City of Hercules
Las Gallinas Valley Sanitation District
Millbrae Waste Water Treatment Plant
Mountain View Sanitary District
Napa Sanitation District
Novato Sanitation District
City of Palo Alto
City of Petaluma
City of Pinole
Rodeo Sanitary District
City of Saint Helena
City and County of San Francisco
City of San Jose/Santa Clara
City of San Mateo
Sausalito/Marin City Sanitation District
Sewerage Agency of Southern Marin
San Francisco International Airport
Sonoma County Water Agency
South Bayside System Authority
City of South San Francisco/San Bruno
City of Sunnyvale
Marin County Sanitary District #5, Tiburon
Union Sanitary District
Vallejo Sanitation and Flood Control District
West County Agency
Town of Yountville

Industrial Dischargers:

C & H Sugar Company
Chevron Products Company
Dow Chemical Company
Exxon Company, USA
General Chemical Corporation
Rhone-Poulenc
Shell Martinez Refining Company
TOSCO Refining Company, Avon Refinery
TOSCO Refining Company, S.F. Area Refinery at Rodeo
USS-POSCO Industries

Cooling Water:

Pacific Gas and Electric

Stormwater:

Alameda Countywide Clean Water Program
Caltrans
Contra Costa Clean Water Program
Fairfield-Suisun Urban Runoff Management Program
Marin County Stormwater Pollution Prevention Program
City and County of San Francisco
San Mateo Countywide Stormwater Pollution Prevention Program
Santa Clara Valley Urban Runoff Pollution Prevention Program
Vallejo Sanitation and Flood Control District

Dredgers:

Aeolian Yacht club
Benicia Marina
California Department General Services
Caltrans
Chevron Products Company
Clipper Yacht Harbor
Exxon Company, USA
Galilee Harbor
Glen Cove Marina/Western Waterways
Loch Lomond Marina
Michael Jackson
Port of Oakland
Port of Redwood City
Port of Richmond
Port of San Francisco
San Leandro Marina
San Francisco Parks and Recreation
San Francisco Yacht Club
TOSCO Corporation
US Army Corps of Engineers

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(as of 1/22/01)

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Cooling Water	Steve Gallo, Southern Energy
Stormwater Agencies	Jim Scanlin, Alameda County Clean Water Program
Dredgers	Jon Amdur, Port of Oakland
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(as of 1/22/01)

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