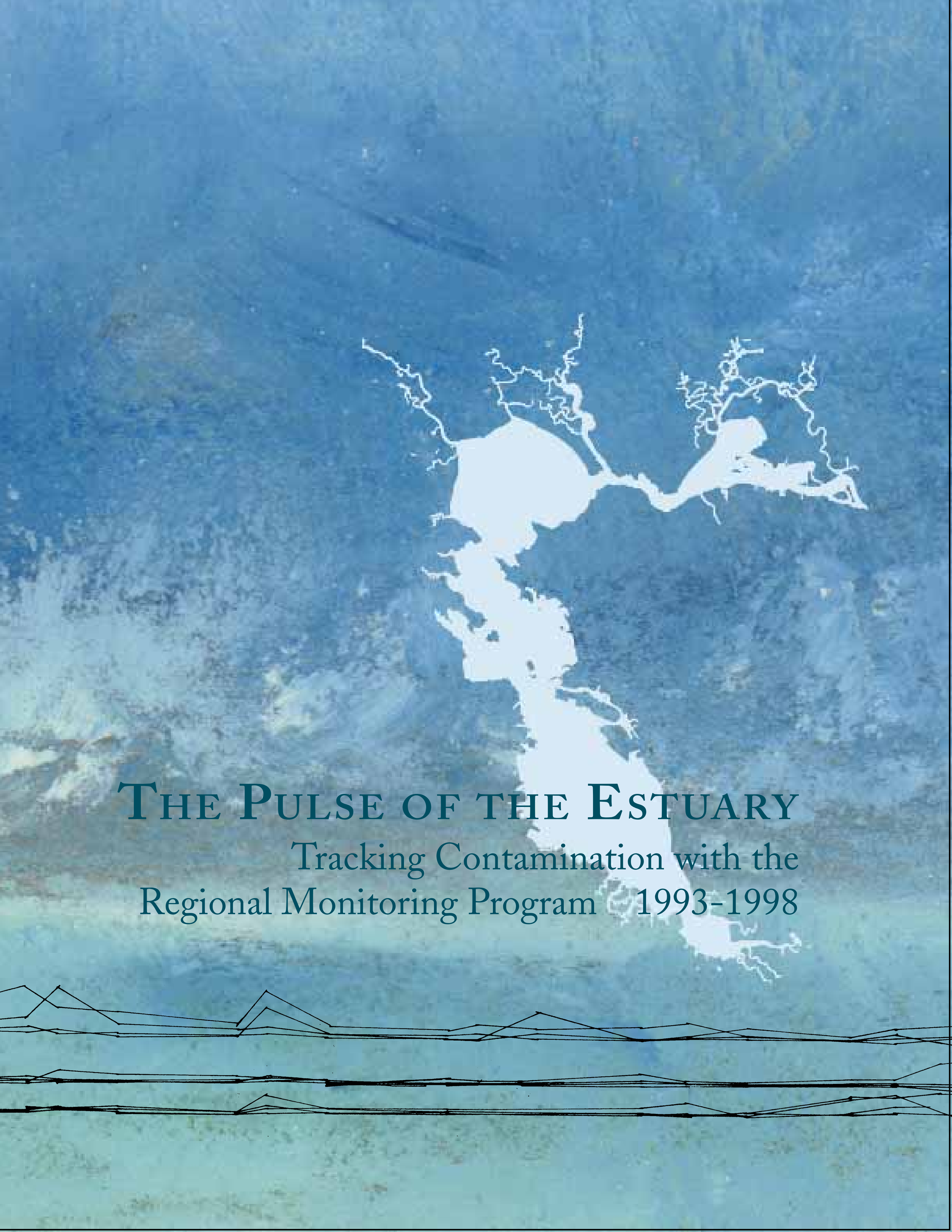

The Pulse of the Estuary

Tracking Contamination with the Regional Monitoring Program 1993-1998

About this Report

This publication represents a new style of reporting for the San Francisco Estuary Regional Monitoring Program (RMP).

The fundamental purpose of the RMP is to provide information to improve the management of the San Francisco Estuary and protect what we value about the Estuary (SFEI 1998a). The intent of *The Pulse of the Estuary* (hereafter referred to as *The Pulse)* is to help fulfill that purpose by improving the dissemination of RMP contamination monitoring results and the use of those results by those who decide how the Estuary is managed.

In order to reach a broad audience, we have prepared a document that is shorter and less technical than previous RMP annual reports. *The Pulse* seeks to:

- emphasize the big picture by presenting key findings from the RMP monitoring effort as a whole;
- highlight the main contamination concerns; and
- make connections between monitoring results and Estuary management decisions.

In order to increase its usefulness to environmental managers, *The Pulse* initiates an explicit effort to explore managerial implications of monitoring results and connect results (i.e. contaminant trends) with management actions such as contaminant discharge regulation.

The Pulse is one of three RMP reporting products for 1998. The second product, *1998 RMP Monitoring Results*, is available on SFEI's web site and includes comprehensive charts and data tables in the style of previous annual reports. The third product is the *RMP Technical Reports* collection. Each of these reports addresses a particular aspect of the RMP or Estuary monitoring. A list of all technical reports produced or in preparation since the last annual report is found on page 27.

An Initial Effort

We consider this report a *work in progress*. In future years each section, particularly the management sections, will be more detailed and complete, and more links will be made between monitoring results and management actions. A key component of future reports will be input from the main water quality regulatory agency of the Estuary, the Regional Water Quality Control Board, and further integration with other studies of San Francisco Estuary contamination. New graphical depictions of Estuary condition will also be introduced.

We welcome your comments on this report.

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Copies of this report can be obtained by calling SFEI at (510) 231-9539.
This report is available on the web at www.sfei.org/rmp.

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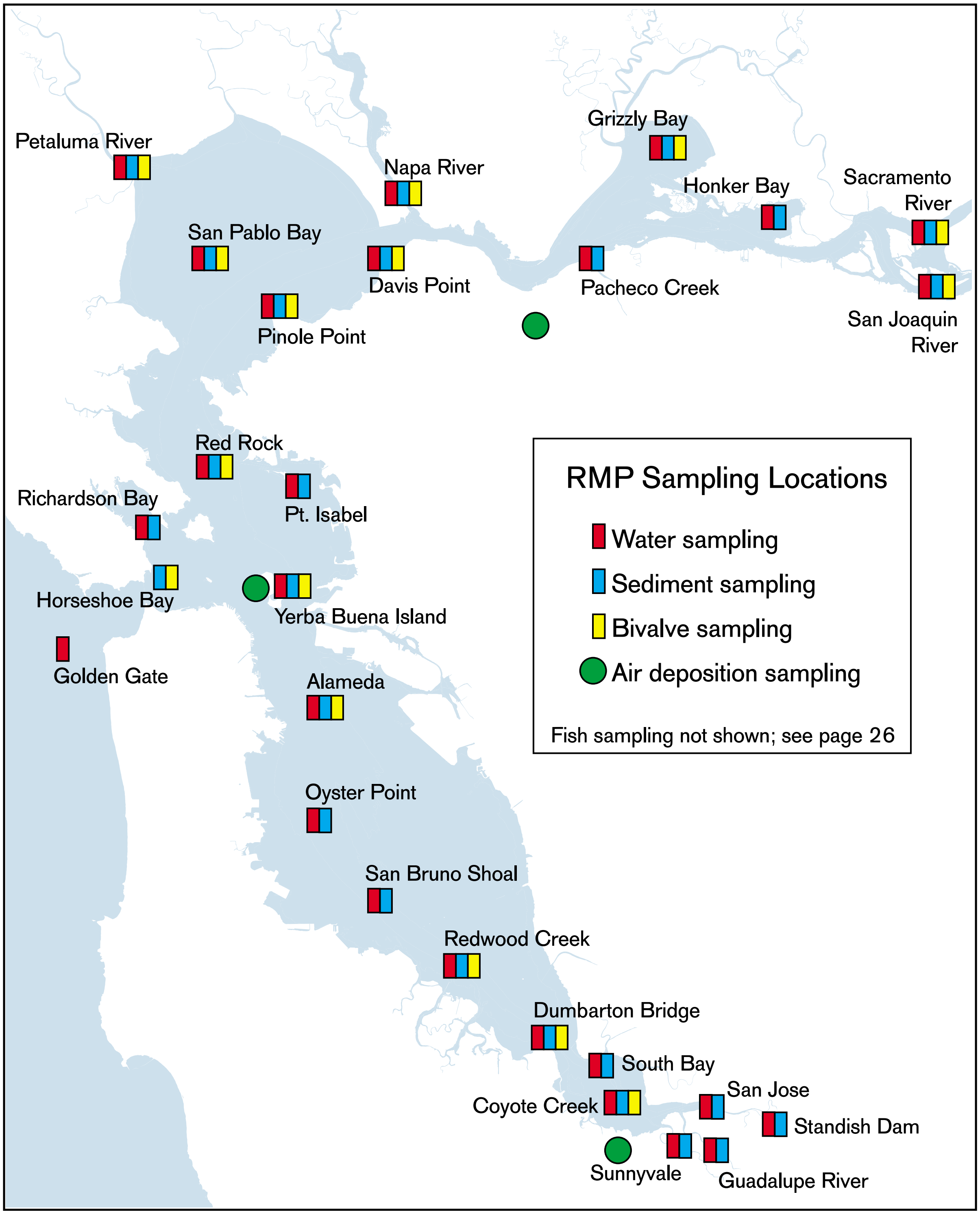
Bay vs. Estuary

Although most people still refer to the expanse of water inside the Golden Gate as "San Francisco Bay," increasingly the term "San Francisco Estuary" is used. An estuary is a place were fresh and salt water meet. San Francisco Estuary refers to both San Francisco Bay and the Sacramento/San Joaquin River Delta. Using the term Estuary avoids some geographic ambiguity, such as if Suisun Bay is part of San Francisco Bay.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Grizzly Bay
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San Joaquin River
Red Rock
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Introduction

The Need to Monitor the Estuary

Monitoring is essential to the proper management of the San Francisco Estuary. In order to manage the Estuary, it is necessary to understand its condition and how that condition changes. Monitoring is needed to assess condition, identify problems, and estimate problem severity. Monitoring can also help determine how to address a problem by indicating if past management actions have made a difference. This is one of the most useful functions for a monitoring program. In practice, it is also one of the most difficult.

Chemical contamination, the topic of this report, is an important aspect of Estuary condition that should be monitored. The dense urban, industrial, and agricultural development in the watershed of the Estuary has resulted in chemical contamination. Rivers, creeks, storm drains, and industrial and municipal outfalls continuously carry contaminants into the Estuary. The populations of many aquatic organisms of the Estuary have declined markedly in the past 150 years and contamination has played a role (SFEP 1992). Current levels of contaminants also pose health risks to humans. Anglers are currently advised to limit their consumption of Estuary fish (OEHHA 1994). Clearly, contaminants in the Estuary must be tracked.

Proper management of the contamination of the Estuary requires answers to some basic questions:

Is the contamination severe enough to harm the Estuary?

The most direct way to measure harm is to monitor the health of Estuary organisms. It is seldom possible, however, to conclusively link the health of organisms in the Estuary to contaminant concentrations. Another way to approach the question of harm is by developing contaminant concentration guidelines and comparing measured concentrations to those guidelines (see *Contaminant guidelines* sidebar). Guidelines are an attempt to answer the question, "is this level of contaminant a problem or not?" Comparison to guidelines is a key component of this report.

Where is the contamination coming from?

Monitoring can identify contaminant sources and pathways (see *Source vs. Pathway* sidebar, page 4). The RMP has produced little information on sources or pathways thus far, as it was not initially designed to do so. More attention is now being paid to this area, and better information on contaminant sources and pathways is expected in the coming years from both the RMP and other monitoring efforts.

How can the contamination best be reduced or eliminated?

Monitoring results can aid decisions on how to best reduce or eliminate contamination problems by identifying sources and by documenting the effects of past contaminant control measures.

The Regional Monitoring Program works to answer these questions.

Regional Monitoring Program Objectives

- To describe patterns and trends in contaminant concentration and distribution;
- To describe general sources and loadings (inputs) of contamination to the Estuary;
- To measure the effect of contaminants on selected parts of the Estuary ecosystem;
- To compare monitoring information to relevant water quality objectives and other guidelines;
- To synthesize and distribute information from a range of sources to present a more complete picture of the sources, distribution, fates, and effects of contaminants in the Estuary ecosystem.

The objectives regarding sources, contaminant effects, and information distribution are new as of 1998.

Contamination

The terms contamination and pollution are often used interchangeably and indicate concentrations of natural and man-made chemicals that are higher than normally found in nature.

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. Estuary fish and birds, or the ability to eat fish we catch in the Estuary) 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 aquatic organisms and the humans and other animals who eat those organisms 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 be additive or synergistic, 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. One of the contributions of the RMP has been to provide information that helps evaluate contaminant guidelines.

next page

In order for monitoring to fulfill its role in managing the Estuary, the numbers produced in the laboratory must be interpreted and judgements made. This responsibility falls on both the scientists conducting the monitoring, who must present monitoring results in a way that can be understood by management, and the managers, who must determine if the information presented warrants action.

Origin and Structure of the RMP

The Regional Monitoring Program for Trace Substances was created by the San Francisco Bay Regional Water Quality Control Board (Regional Board) to provide accurate information on chemical contamination in the Estuary. The innovative structure of the RMP is a collaboration between the Regional Board (the local regulatory agency implementing the Clean Water Act and the California Water Code), the regulated entities that fund the Program (currently 83 wastewater dischargers and dredgers), and the San Francisco Estuary Institute, an independent non-profit scientific research organization.

Report Format

Each section of this report presents the following aspects of Estuary contamination:

- **Status**: What are the current contamination levels?
- **Trends**: Is the contamination getting better or worse?
- **Cause** or **Sources**: How did the contaminants get in the Estuary?
- **Effects**: What harmful effects have been documented or may be occurring in the Estuary?
- **Cure**: **Management action**: What management actions in the past have likely affected the contamination seen today? What upcoming or potential management actions could affect the contamination in the future? How should management respond to monitoring results?

This format is designed to parallel the thought process of an Estuary manager addressing contamination issues. Addressing all these aspects of Estuary contamination in a meaningful way is a challenging task. Currently, much is unknown and much of what is known has not been assembled in a meaningful way. This format acknowledges that successful management of the Estuary requires answers in all areas.

The RMP alone cannot provide all the answers, but the Estuary community as a whole must. *The Pulse*, by reporting RMP results and other monitoring and management work, documents our progress in finding the answers.

continued

For sediment, the guidelines used in this report 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 water, guideline development considers both laboratory studies and field observations, and is aimed at protecting a particular set of qualities we value, known as "beneficial uses." The Regional Water Quality Control Board, a state agency, has the responsibility for setting water guidelines, with guidance from the US Environmental Protection Agency. The water guidelines are legally enforceable.

For fish, the guidelines, calculated by the Regional Board with the help of the U.S. Environmental Protection Agency, aim to protect the human consumers and consider what is known about human responses to ingesting contaminated fish.

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.

RMP Monitoring: What, Where and Why

Detailed sampling and analysis methods are available in the *RMP Field Operations Manual* and the *Quality Assurance Program Plan* (SFEI 1998b).

Water and Sediment

Water and sediment are two fundamental components of the Estuary. They provide habitat for most of the Estuary's life, including the foundation of the estuarine food web—phytoplankton that create food via photosynthesis.

Contaminants

The RMP analyzes for a suite of contaminants from three groups: trace elements, synthetic organics, and polycyclic aromatic hydrocarbons (PAHs) (see *Contaminant Names and Categories* box). The contaminants chosen are those subject to local, state and federal regulation. For monitoring to provide a comprehensive view of contamination concerns in the Estuary, all potentially harmful contaminants should be tracked. However, many contaminants that may pose environmental risks are currently not measured (see *Unidentified contaminants* heading, page 7).

Sites

The RMP samples water and sediment from sites located throughout the Estuary: from the ends of the Sacramento and San Joaquin Rivers near Antioch, to near the Golden Gate, to small channels in the creeks of the South Bay. Currently, there are 26 water sites and 24 sediment sites (see figure, page 2).

Contaminant Names and Categories

This is an organizational list of contaminant names and categories used in this report. Details on some of these contaminants are provided in later sections.

Trace elements—most measured trace elements are metals and are referred to as such. Trace elements include mercury, copper, nickel, lead, and nonmetals such as selenium.

Organics—compounds of carbon

Synthetic organics—compounds created by humans
- PCBs (polychlorinated biphenyls)—industrial chemicals
- Organochlorine pesticides—the use of these compounds is banned
  - DDT
  - dieldrin
  - chlordane
- Organophosphate pesticides (OPs)—these compounds are in current use
  - diazinon
  - chlorpyrifos (a.k.a. Dursban)

Other organics—unintentional chemical by-products
- PAHs (polycyclic aromatic hydrocarbons)—by-products of combustion and manufacturing; found in crude oil
- Dioxins—by-products of combustion and manufacturing

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 play a role. Determining how those variables may interact to create harm is a daunting task.

A more direct approach to assessing potential harm, which avoids many of the difficulties of interpreting contaminant concentrations, is to expose organisms (e.g. mussels or shrimp) in the laboratory to Estuary water or sediment 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). When contaminant mixtures are present, conclusive identification of exactly what is causing the toxicity is often not possible. The RMP plans to increase the use of TIEs on water and sediment samples.

The RMP is evaluating whether to move sampling sites in order to better identify the paths of contaminants to the Estuary. Most RMP water and sediment sampling sites are in deep water away from the shoreline. These sites were chosen to try to measure "background" Estuary conditions, conditions apart from local influences such as nearby wastewater discharges. However, some samples are also taken at potential contaminant entry points, such as river and creek mouths. There are a few of these sites, such as the Petaluma River mouth and sites on Coyote Creek and Guadalupe River. Since a new RMP objective is to identify sources of Estuary contamination, the RMP will probably add more such sites in the future. Quantifying contaminant entry from pathways such as rivers is an important step towards the ultimate goal of identifying the sources (see *Source vs. Pathway* sidebar, page 4).

Toxicity

Toxicity testing is performed in the laboratory by exposing organisms to water and sediment from selected sampling sites. Tests to identify the causes of toxicity are also performed (see *Toxicity testing* sidebar).

Toxicity test results from the RMP have led researchers to suspect that water in some areas may be toxic to Estuary organisms for several days after rainfall, as contaminants are washed off the land into the Estuary. Recent sampling is oriented towards catching these *episodic toxicity* events.

Bivalves

As another measure of water quality, the RMP collects living bivalves (mussels and oysters) from clean locations outside the Estuary and places them in the Estuary for three months. The bivalves' tissue is then analyzed for contaminants. This "mussel watch" technique has long been used to monitor water quality (Phillips 1988).

There are several reasons to use bivalves to assess water quality. The RMP takes water samples only three times a year, while bivalves act as continuous water samplers and provide an integrated picture of water quality for the time that they are placed in the Estuary. Variation in conditions such as salinity and food availability can influence their contaminant uptake in unknown ways, however. Bivalves also provide an indication of the *biologically available* portion of water contaminants—those contaminants forms that can actually contribute to harming Estuary life.

Air deposition

One pathway for contaminants to the water and sediment of the Estuary is direct deposition from the air. Microscopic airborne contaminants, arising from motor vehicles, incinerators, or industrial sources, can settle directly on the surface of the Estuary during both rainstorms and dry periods. To assess the significance of the atmosphere as a path for contamination, the RMP is taking measurements at three locations around the Estuary. Five metals are being measured, and organic contaminants such as PAHs, PCBs, and dioxins may be monitored in the future.

Wetland sediment

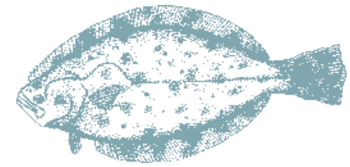
Wetlands are the site of some of the most important ecological activity in the Estuary, and can also act as contaminant traps. Wetland sediment was sampled in 1995 and 1996 from Petaluma and China Camp marshes (Collins and May 1997).

Estuary Benthos

"Benthos" refers to animals such as worms, clams, and amphipods that dwell in the sediments of the Estuary. By tallying the kinds and abundances of organisms in the sediment and comparing results from different locations, patterns may emerge that suggest contaminants are affecting the benthos. Since the benthos are actual residents of the Estuary, this is a direct measurement of Estuary condition. This is the only direct measurement of Estuary condition used by the RMP.

Estuary Fish

Many people catch and eat fish from the Estuary. For some residents, locally caught fish are an important source of food. Fish are monitored by the RMP to help health agencies determine if fish consumption could be harmful to human health, and to provide an indication of contaminant intake by nonhuman fish consumers. Another reason to monitor fish is, like bivalves, they can be considered continuous water samplers and can tell us about long-term contamination trends and spatial patterns in the Estuary. Fish are analyzed for a subset of RMP contaminants and for dioxins. The choice of species analyzed (striped bass, white croaker, halibut, leopard shark, shiner surfperch, sturgeon, and jacksmelt) was based on angler catch and fish consumption surveys. Fish sampling was performed in 1994 and 1997 and is scheduled to continue every three years (SFEI 1999b). The next round of sampling is scheduled for June 2000. In 1997, fish were sampled from seven locations around the Estuary.



Not Monitored: What, Where and Why Not

Unidentified contaminants

There are many contaminants in the Estuary that the RMP does not identify or quantify. To date, the RMP has relied on lists of regulated contaminants to decide what to measure.

In the past, a contaminant's presence at levels high enough to cause harm frequently became known only after damage to the environment had already been done. At that stage, corrective steps require more effort and resources than if earlier detection and intervention had occurred. Plans are being made to measure additional contaminants that represent potential future contamination problems.

The RMP is planning to develop a "surveillance" component to identify and measure chemicals that have not received much regulatory attention, such as flame retardants, softening agents in plastics, and mosquito repellent additives, but for which evidence of adverse effects is growing. This component will include tracking the scientific literature on the toxic effects of compounds not yet measured by the RMP but probably present in the Estuary, and building a library of potentially troublesome contaminants to be measured periodically by the RMP.

Thus, in the future the RMP will not only look at whether established goals for environmental improvement are being met, but also if any new, emerging problems might require proactive management intervention.

Wastewater outfalls

The RMP has intentionally not located sampling sites near wastewater outfalls. Other studies have examined contamination from specific outfalls (Thompson *et al.* 1999a), and the dischargers themselves analyze their wastewater as required by the Regional Water Quality Control Board.

Toxic hot spots

There are known "toxic hot spots" in the Estuary, areas that due to industrial uses are particularly toxic from one or more contaminants. The RMP does not monitor these sites, as the RMP's focus is more regional and another program, the Bay Protection and Toxic Cleanup Program, is addressing the issue of toxic hot spots (Hunt *et al.* 1999). Investigations are currently being conducted on the sites of highest priority.

Wetlands

The RMP no longer samples wetland sediments because other non-RMP efforts are underway to establish regular wetlands contamination monitoring in the Estuary (Collins, pers. comm.). In addition, wetland sampling was done on a trial basis and other priorities prevented continuation of sampling.

Problem prevention

There are thousands of synthetic chemicals currently in use for which the environmental effects are inadequately known. Recognizing this disconcerting situation, some European countries have tried to forestall possible ecosystem damage by tracking environmental concentrations of such chemicals *before* evidence of problems is found. The RMP is currently planning such preventive monitoring.

Most resident organisms

Contamination in Estuary residents other than fish and benthic organisms is not currently examined by the RMP. Analysis of birds, seals and other residents could yield important information about food web contamination, contaminant trends and human health risks. Some organisms may be more useful in this regard than others. These analyses are expensive, and priorities must be carefully set to make best use of the RMP's limited funds. Bird egg measurements may begin in 2002.

Biological contamination

Biological contamination of the Estuary is not addressed by the RMP. This includes pathogen concentrations and invasive species.

San Francisco Estuary Contamination–The Big Picture

The following statements represent some important aspects of current thinking regarding contamination and the management of contamination in San Francisco Estuary. They are based in part on the results of the RMP, and provide a context in which to view future results. They should not be regarded as proven fact, but rather as working assumptions.

1. **The Estuary is impaired by contamination.** Estuary life is currently impaired by excessive levels of several contaminants including mercury, pesticides and PCBs (SFEI 1999c; SFEI 1999d).
2. **Management action has reduced inputs**. For many identified contaminants of concern, there is a good understanding of how a progressive series of management actions (such as wastewater quality requirements) have reduced the input of these contaminants from discrete sources such as industrial plants and wastewater treatment plants (SFEI 2000).
3. **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 disturbance of these sediments by wind-agitated water, high tidal and river currents and dredging causes contaminants to re-enter Estuary water (SFEI 2000).
4. **Untracked contamination problems may be significant.** Potentially large 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, that could cause such problems. Remedies are planned. See *Unidentified contaminants,* page 7.
5. **Much of the ongoing contamination is from small sources.** The bulk of the *ongoing* inputs of contaminants of concern comes from numerous sources scattered around the Estuary (i.e., cars, erosion, small spills, etc.). Contamination from these sources is typically moved to the Estuary by rainwater via rivers, creeks and storm drains. These dispersed small sources are not easily controlled through traditional regulatory approaches.
6. **Contamination is best controlled by prevention.** The best way to control the remaining contaminant inputs to the Estuary is most likely to focus on the numerous small contaminant sources through pollution prevention activities and general watershed management (SFEI 2000).

Top Known Contamination Problems

Over the last six years, the RMP has detected many contaminants at levels above what is considered safe. Results indicate that the following contamination problems warrant particular concern. Significant problems involving unmonitored contaminants may also exist (see *Unidentified contaminants,* page 7).

Problem: High PCBs and mercury in water and fish

Why is this a problem?

The widespread presence of PCBs and mercury has the potential to harm humans and wildlife that consume fish from the Estuary (see figures, page 10). In addition, these contaminants may be harming the fish themselves.

Trends

While PCB levels have dropped from their maximum in the early 1970s, there is no clear indication of continued decrease in recent years (SFEI 1999d).

The expectation for the future is that PCB concentrations will drop very gradually. Estuary sediments contain large amounts of PCBs that are stirred into the water by wind-agitated waves, river or tidal flow, or dredging.

Data from the RMP indicate mercury levels in water have been stable over the last six years. The future trend will probably be similar to that for PCBs, as large masses of mercury are also found in Estuary sediments and in the sediments of rivers leading to the Estuary. The sediments of some large portions of the Estuary are eroding, causing continuing inputs of mercury to the water.

Cause

Leakage from or improper handling of equipment containing PCBs has led to

Mercury (Hg)

Mercury is naturally abundant in the rocks of the Coast Range of northern 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 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 leakage and mining debris deposits in upland watersheds (SFEI 1999e).

Mercury is found in several forms, some of which have much greater potential for harm than others. Methylmercury is the form of greatest concern and is produced by bacterial action in sediment. Some forms of mercury are particularly susceptible to this bacterial transformation and also warrant special concern.

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 fetuses and children as their nervous systems develop. Mercury has also been found to have harmful effects on the kidneys, brain, and the respiratory, cardiovascular, circulatory, immune, and reproductive systems.

Case Study: New Almaden Mine

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 readily 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 are readily found in samples taken anywhere from New Almaden down to San Jose.

widespread contamination of Estuary watersheds and subsequently the Estuary itself.

A recently developed PCB budget for the Estuary suggests there are continuing inputs of PCBs to the Estuary, in spite of the ban on their sale and production in 1979 (SFEI 1999d). 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. Local U.S. Environmental Protection Agency (USEPA) staff estimate that 5% of the total amount of PCBs produced are still in use (Carter, pers. comm.) A recent voluntary survey conducted by the USEPA found that nine Bay Area organizations still have 200,000 kilograms of PCBs in use in electrical transformers. This is approximately 400 times the quantity of PCBs currently estimated to be in Estuary sediments (SFEI 1999d).

Little is known about the proportion of PCBs that enter the Estuary from each of the suspected pathways.

Much of the mercury contamination in the Estuary stems from mercury mining and its former use in processing gold ore. California's long history of gold and mercury mining has resulted in large deposits of mercury-laden sediments in the Estuary, and mercury in upstream sediments continues to wash in to the system (SFEI 1999e). Another pathway of mercury that may be of similar magnitude is the runoff from urban areas. Additional likely smaller mercury pathways include discharge from industry, municipal wastewater treatment plants, and particles directly entering the water from the atmosphere. Current RMP air monitoring efforts should soon yield a good estimate of the magnitude of atmospheric inputs.

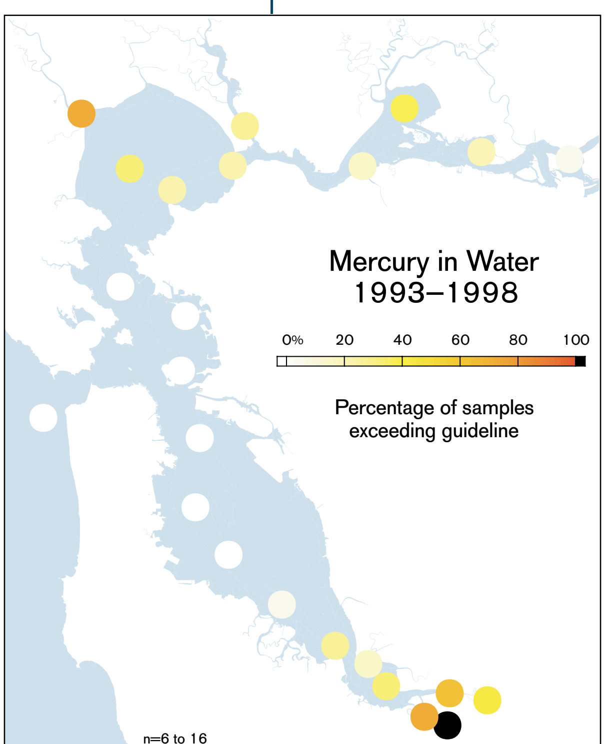
The total amount of mercury entering the Estuary is actually of secondary concern to the production of one particular form, known as methylmercury. The most toxic form of mercury, methylmercury is created from other forms of mercury through bacterial action in sediments. Some forms of mercury are more easily changed to methylmercury than others. There is little known about the location of important sites of methylmercury production in the Estuary, and how much methylmercury is contributed by rivers, streams and storm drain outfalls. The RMP did not directly measure methylmercury in the past, but does now. The Regional Board, in collabora-

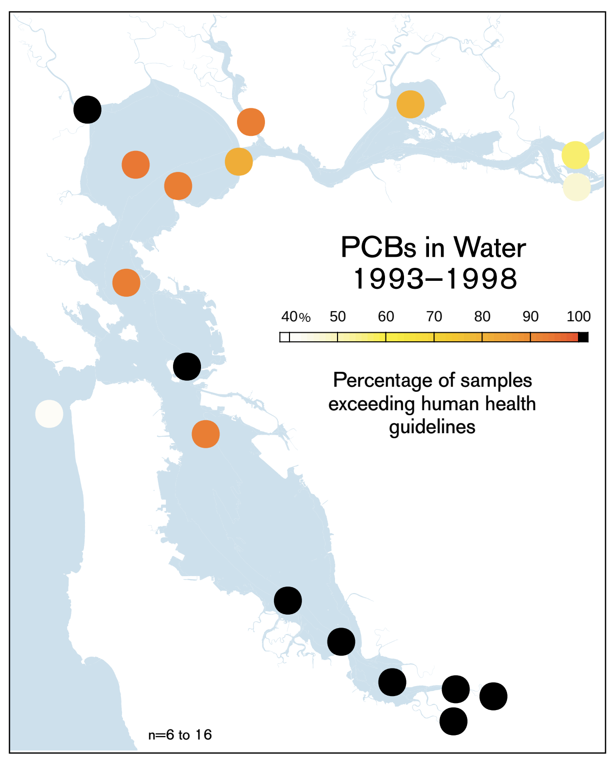
Polychlorinated biphenyls (PCBs)

PCBs are a group of over 200 organic chemicals with a number of characteristics that made them useful to industry. The primary uses of PCBs, manufactured from 1929–1979, were as insulating materials in electrical transformers, plasticizers, hydraulic fluids, lubricants, and they were used 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 extreme 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. PCBs are extremely toxic in long-term exposures and can cause developmental abnormalities, disruption of the endocrine system, impairment of immune function, and cancer promotion.





tion with the Central Valley Regional Water Quality Control Board and the Estuary management effort known as CalFED, is investigating where and how methylmercury is formed in the Estuary and what mercury inputs are most readily converted to methylmercury.

Effects

Much more work has been done on documenting the contaminant levels in the Estuary than on the more important question of impacts of the contaminants on Estuary life. This is mainly because of the difficulty of linking the condition of organisms in the field with any particular environmental variable. 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 Regional Board through CalFED is currently conducting a study of the effects of mercury on the development of bird eggs. Documentation of ecological effects due to PCBs and mercury in the Estuary is needed.

Cure: Management action

Concern over human health has caused the state Office of Environmental Health Hazard Assessment to post an interim consumption advisory for fish caught in the Estuary (OEHHA 1994). This advisory was issued in 1994 and extended after a review of 1997 monitoring results (SFEI 1999b).

Little can be done about the large deposits of PCB and mercury-laden sediments in the Estuary, except to allow time for natural processes to deeply bury or transport the contaminants to the ocean. If new inputs of these contaminants continue however, as appears the case today, concentrations can be expected to decline very slowly at best. Inputs must be reduced or stopped to accelerate the declines.

The ban of PCB sale and production in 1979 was a key management action needed for control of PCB contamination. Management of continuing PCB inputs to the Estuary is hampered by the lack of knowledge about those inputs. If inputs were stopped completely, which is probably not possible, PCBs would become less of concern in perhaps a decade or two (SFEI 1999d).

Concern over the PCB problem has resulted in the application of a special management approach known as a total maximum daily load (TMDL; see *The Clean Water Act and TMDLs* box).

Mercury contamination concerns led the U.S. to ban directly combining mercury with ore for gold extraction. Mercury continues to wash from mine sites and mining debris deposits throughout the Estuary watershed.

The mercury problem is also being addressed through the TMDL process. Municipal and industrial wastewater dischargers have made significant efforts to determine how much mercury they put into the Estuary. An important next step in TMDL development is to better estimate the amount of mercury entering the Estuary from other, larger pathways, including storm drains, rivers and streams, and from the air.

To effectively manage the mercury problem, the production of methylmercury in the Estuary must be reduced. 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

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." Under the Clean Water Act, clean up 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.

goal of removing harmful effects. The RMP can play a vital role by tracking the distribution of methylmercury concentrations in the water and sediment of the Estuary.

Problem: Water is periodically toxic

Why is this a problem?

When Estuary water is found toxic to lab organisms (see *Toxicity testing* sidebar, page 6), it is an indication that organisms in the Estuary are probably being harmed. Zooplankton populations in the Estuary have dropped to one-tenth to one-twentieth their size in the 1970s (Obrebski *et al.* 1992), and this reduction in a pillar of the food chain may be partly due to the contamination that is causing toxicity.

Trends

Most occurrences of water toxicity in the Estuary appear to be directly related to rainstorms. Toxicity sampling immediately following a major rainstorm did not occur until the winter of 1996–1997. In years prior to 1996, water toxicity was rarely seen by the RMP. Since 1996, water samples from sites in the North Bay and South Bay that coincided with significant rainfall have frequently been toxic (SFEI 1999c). During two time periods in 1998, 3 consecutive samples taken at 2 to 3 day intervals in the North Bay were all toxic, suggesting that extended periods of toxicity occur.

Water toxicity is expected to continue to be detected in the future, as the practices that are likely the primary cause have not changed significantly.

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 1995).

Organophosphate pesticides

Once the environmental threat posed by organochlorine pesticides such as DDT was recognized, that class of pesticides was gradually replaced by organophosphate pesticides. Although regarded as much less of a threat than organochlorines, organophosphates are raising 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 this situation can be turned around relatively quickly with appropriate management to prevent continued input of pesticides to the water. Bay Area residents can directly contribute to the resolution of this problem by using alternative methods of pest control.

Cause

Analyses to determine the cause of the toxicity (see *Toxicity testing* sidebar, page 6) observed in RMP water samples have not been conducted. 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 1995). The type of pesticides implicated, known as organophosphates (OPs), are currently used in agriculture and by residents and businesses throughout the region. Rainfall moves these pesticides from the plants and land they were applied upon 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 household, business, and local government use of OPs.

Effects

Toxicity test results clearly show harmful effects from Estuary water on lab organisms, but measurements of actual effects on Estuary life are virtually nonexistent. This is mainly because of the difficulty of linking the condition of organisms in the field with any particular environmental variable. The toxic episodes observed do 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 depopulation of North Bay zooplankton, thought to be mainly the result of an introduced clam, may also be related to water toxicity. Studies to document the ecological effects of water toxicity are needed.

Cure: Management action

Currently, local governments throughout the region are engaged in public information campaigns to try to reduce the amount of OP pesticides used by residents and limit application to periods when no rain is expected.

Progress on determining the nature of the link between North Bay toxicity and pesticide applications in the Central Valley will be greatly aided if the data on pesticide applications are compiled and made available in a more timely manner (SFEI 1999c).

Based on the results of numerous studies, the Sacramento and San Joaquin rivers and the Delta are officially designated by the State as impaired by contamination. Under the Clean Water Act, such designation sets in motion a process to determine the reasons for the impairment and create a plan to address the impairment. Although toxicity testing has produced abundant evidence that OP pesticides are causing impairment, no comprehensive plan to address OP contamination has been made. This is because the State Department of Pesticide Regulation (DPR), which has been given the authority for regulating pesticides, has a different threshold for action than the water quality regulators. This suggests that current results may need to be augmented by studies designed to prove adverse effects on organisms that actually live in the river and Delta, if they are to result in regulatory action (SFEI 1999c).

The repeated occurrence of water toxicity in the Estuary has led the Regional Board to apply a special management approach known as a total maximum daily load (TMDL; see box on page 11.). A better identification of the toxic agents is needed for this approach.

Problem: Sediment is toxic

Why is this a problem?

When Estuary sediment is found toxic to organisms in laboratory tests (see *Toxicity testing* sidebar, page 6), it is an indication that life in the Estuary is probably being harmed. Sediments provide habitat to many Estuary organisms that are important parts of the Estuary food chain.

Trends

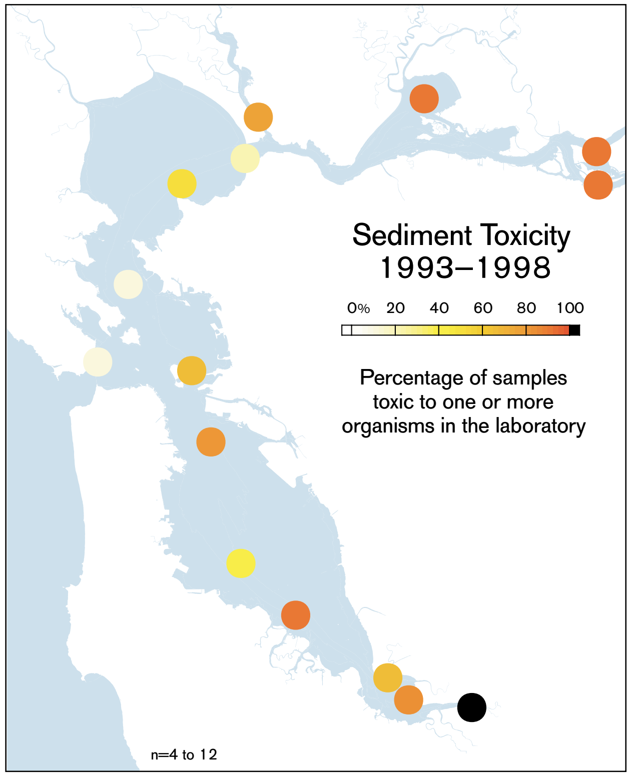
Over the past six years, 70% of RMP sediment samples were toxic to at least one of two lab organisms (see figure, next page). Year to year, the proportion of toxic sediment samples ranged from 13% to 100%, with no clear overall trend. At one site, Yerba Buena Island, the occurrence of toxic sediments 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 contaminant inputs, and the slow rate of the burial process that renders the contamination benign.

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 remain suspended in the air and be deposited directly onto the surface of water during rainfall or through dust particles. PAHs also attach to particles that settle on the ground and can be transported through storm water runoff, when rain carries PAHs from the surfaces of streets and parking lots into channels, creeks, and ultimately the Estuary. Higher concentrations of PAHs are found in urbanized portions of the Estuary.

When PAH residues 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 impairment of 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. PAHs, particularly the larger PAH molecules, are among the most potent carcinogens known.



Cause

The sediments of the Bay contain a variety of contaminants from a variety of sources. Analyses to identify the cause of the sediment toxicity have not yielded consistent answers, probably in part due to the complex mixtures of chemicals involved. In some cases, metals are implicated as a causative agent, in others pesticides or PAHs are suggested. Different contaminants are implicated at different sites at different times. It is likely that a combination of contaminants is often responsible (Thompson *et al.* 1999b; Anderson *et al.* 2000; Phillips *et al.* 2000). Results thus far are not conclusive, and work to identify the toxic agents continues.

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). The concentrations of these contaminants suggest they may play a role in sediment toxicity.

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. This is mainly because of the difficulty of linking 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 a reduction in the population of contaminant-sensitive species. Changes in benthos can impact the many benthic predators in the Estuary. Studies to further document the ecological effects of sediment toxicity are needed.

Cure: Management action

It may be practical to clean up some of the Estuary's contaminated sediment by removing the sediment or capping the area with clean sediment. A large part of the cure for toxicity in the sediment is probably time. A key management action required, banning the use of DDT, chlordanes and similar long-lived organochlorine pesticides, occurred between 1972 and 1988. It will likely be decades before degradation, burial, and transport to the ocean drop organochlorine concentrations to acceptable levels in the Estuary.

Organochlorine contamination may be just one part of the problem, however. PAH contamination is an emerging issue. Since PAHs typically enter the air, then travel to water, and then to sediment, effective PAH management will demand cross-jurisdictional coordination between land-use managers and air and water regulatory agencies.

Air quality controls to reduce PAH emissions to the atmosphere may be helpful and increasingly important as the number of people and cars near the Estuary increases. Without a clear knowledge of exactly what is causing toxicity, a clear path to resolving the problem is not yet apparent.

Since 70% of the sediment samples collected by the RMP were toxic, any project involving the movement or use of Estuary sediment, such as dredging, wetland creation, or shoreline improvement, should proceed with caution.

Contamination of Water, Sediment and Fish

Water

Status

The San Francisco Bay Regional Water Quality Control Board (Regional Board) has the primary responsibility for protecting water quality in the Estuary, and water quality objectives are the primary yardstick used by the Regional Board to determine whether the levels of a contaminant in the Estuary are too high (see *Contaminant guidelines,* page 3).

The RMP measures concentrations of many contaminants in the waters of the Estuary and compares these concentrations to water quality objectives. These comparisons are summarized in the table below, which can be considered a major component of a water quality "report card" for the Bay. The concentrations of five metals have frequently exceeded water quality objectives in the RMP: chromium, copper, mercury, nickel, and zinc. Several organic chemicals have also frequently exceeded objectives, including PCBs, DDTs, chlordanes, dieldrin, and PAHs. PCBs have the worst track record of all of these problem contaminants.

Some locations in the North Bay (particularly the mouth of the Petaluma River and San Pablo Bay) and all four locations in the lower South Bay exceed water quality objectives more frequently and with more contaminants than other locations (see *Water Quality* figures, page 24). 100% of the samples from these sites contained one or more contaminants above guidelines.

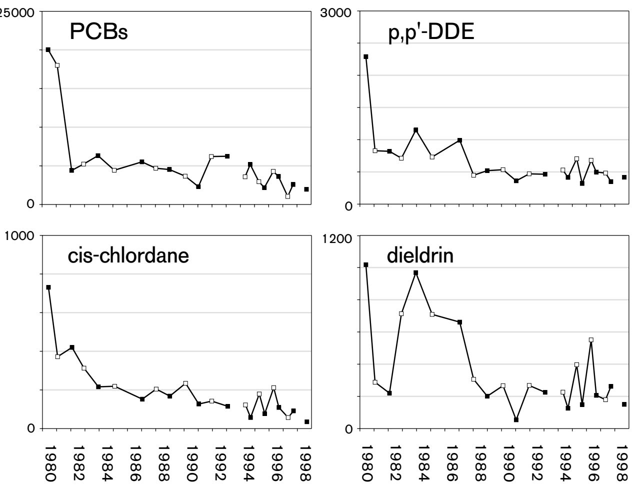
Concentrations of contaminants in fish are another important component of the water quality report card for the Estuary, as fish can be thought of as continuous water

Contaminants relative to water quality objectives. Numbers indicate the percent of samples that met guidelines. 1998 data is preliminary.

	1994	1995	1996	1997	1998
Chromium	94%	91%	93%	85%	82%
Copper	83	85	88	90	97
Mercury	79	80	87	67	75
Nickel	83	83	85	81	84
Lead	96	94	96	90	92
Selenium	100	100	100	97	99
Zinc	96	98	99	92	92
PAHs	61	69	53	59	25
Diazinon	93	100	94	100	100
Dieldrin	80	96	94	55	87
Chlordanes	100	93	84	87	89
DDTs	98	92	90	88	91
PCBs	7	13	8	19	20

samplers. RMP fish tissue sampling performed in 1997 found concentrations of mercury, PCBs, DDTs, chlordanes, dieldrin, and dioxins at levels of potential concern. For more information, see *Fish* on page 21.

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

Evaluating long-term trends in contaminant concentrations in the Estuary is another primary objective of the RMP. 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 the RMP data are considered together with data from earlier monitoring efforts, such as the State Mussel Watch Program and the Bay Protection and Toxic Cleanup Program, sufficient data are available for a meaningful discussion of long-term trends.

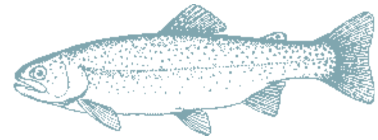
The long-term database with the most complete time series uses transplanted mussels, which were deployed in the Bay from 1980–1993 under the California State Mussel Watch Program and from 1994 to the present under the RMP. Mussels readily accumulate organics such as PCBs and DDT, and are particularly useful for monitoring these chemicals. PCB concentrations in mussels dropped sharply in the early 1980s, then showed no perceptible change from 1982 to 1996 (see figure above). Lower PCB concentrations in 1997 and 1998 may be an indication of a long-term decline. Concentrations of the organochlorine pesticides DDT (represented in figure by relative compound DDE), chlordane, and dieldrin generally were high in 1980, distinctly lower in 1981, and have declined very little since about 1988.

Systematic monitoring of metals in waters of the Estuary began under the Regional Board in 1989 and has been continued under the RMP since 1993. Reliable data from 1979 and 1980 are also available for comparison. In spite of drastic reductions in the input of metals achieved by the ban on leaded gasoline and improvements in wastewater treatment, metal concentrations of lead and other metals in water have changed little in the last 20 years (Flegal *et al.* 1996).

Sources

A group of experts convened by the RMP in 1998 estimated contaminant inputs to Bay waters from the following major pathways: historic sediment deposits, small tributaries and storm drains, direct atmospheric deposition to the Bay surface, the Sacramento and San Joaquin rivers, effluent discharges, and harbor activities including dredging (see *Source vs. Pathway* sidebar on page 4). The group recommended that better estimates for these pathways be obtained through careful review of existing information followed by a series of studies that will address the most critical information needs (SFEI 1999e).

Historic sediment deposits appear to be a major pathway for many contaminants to the waters of the Estuary and are thought to be responsible for the slow decline in water contaminant levels. Many of the persistent contaminants that are currently of concern, such as mercury, copper, PCBs, and PAHs, have a strong tendency to bind to sediment particles rather than become dissolved in water. This contaminated sediment becomes deposited at the bottom of the Bay. Concentrations of contaminants in general were substantially higher in the 1950s and 1960s, so sediments deposited during this period were highly contaminated. Due to the shallow average depth of the Bay, winds and tides cause intense mixing of the sediments. Sediments deposited over the last several decades, including the highly contaminated sediments of the 1950s and 1960s, are continually mixed with the new sediment and resuspended into the water, resulting in exposure of aquatic organisms to the contaminants they carry. The deep mixing of sediment causes concentrations of persistent contaminants in the Bay to respond very slowly to changes in inputs. Because of historic sediment deposits, even if inputs of mercury or PCBs were immediately eliminated, it would still take many years for water concentrations to fall below thresholds of concern. The RMP is planning studies to better understand the effect of historic sediment deposits on contaminant concentrations in the Bay.



Small tributaries and storm drains were also identified as possibly significant pathways that need to be more accurately characterized. Available data suggest that this pathway may carry significant amounts of PCBs, PAHs, diazinon, mercury, copper, and nickel to the Estuary. Much of the contamination carried by small tributaries can be attributed to historical sources in upstream areas that contaminated soils and sediments in the watershed. The RMP and the San Francisco Estuary Institute (SFEI) are currently conducting studies to develop better estimates of inputs from small tributaries and a better understanding of which small tributaries may contribute the largest masses of contaminants.

Direct atmospheric deposition of contaminants to the surface of the Bay may represent a significant input of mercury, PCBs, PAHs, and some other contaminants. A study examining direct atmospheric deposition to the Bay was initiated in the summer of 1999. In its first phase, this study is measuring deposition of mercury, copper, nickel, cadmium, and chromium. Preliminary data collected from September through December 1999 indicate that direct dry deposition of some metals onto the Estuary ranged from 10% to 30% of the inputs from wastewater dischargers, indicating that atmospheric deposition is not a trivial pathway for metals to the Estuary.

The Sacramento and San Joaquin rivers are significant pathways for all of the metals and may be significant for PCBs and PAHs. Discharges from industrial sites and wastewater treatment plants are relatively well characterized, and are a significant pathway for many metals but probably minor for PCBs and organochlorine pesticides. Harbor activities, including dredging, are regulated by state and federal agencies to minimize their input of contaminants. Ongoing work to develop TMDLs for mercury and PCBs (see *The Clean Water Act and TMDLs* box, page 11) will include evaluations of bay bottom erosion, dredging, and dredge disposal activities as potential sources of these contaminants.

Effects

Measurements of adverse effects in the Estuary caused by water contamination have not been made. The RMP evaluates the potential for effects by using aquatic toxicity testing (see *Toxicity testing* sidebar, page 6).

Water toxicity has been observed in two locations: 1) the North Bay from the Napa River to the Sacramento and San Joaquin river stations, and 2) the South Bay. Most of the toxicity observed in the North Bay is associated with large winter freshwater flows entering this portion of the Estuary. However, sustained toxicity was also observed in May 1998 in samples collected over a nine day period. The duration of the toxic episodes in the North Bay is long enough to potentially cause adverse impacts to fish and other aquatic organisms. It is likely that agricultural runoff is the major contributor to the toxicity observed in the North Bay. Toxicity has been observed in several locations in the lower South Bay. Toxicity testing by others of storm water runoff from Bay Area cities has also found frequent toxicity to aquatic organisms.

Pesticides in current use, such as diazinon and chlorpyrifos (a.k.a. Dursban), are suspected to be one of the causes of this toxicity. RMP sampling has detected concen-

Response time

If all contaminant inputs to the Estuary were stopped completely tomorrow, what would happen? All contaminants would begin to decrease, some (such as diazinon) very rapidly, others (such as DDT) very slowly. The delay before a measurable drop in average diazinon concentrations occurred would be measured in weeks, while with DDT it would be measured in decades. This is because, relative to diazinon, there is a lot of DDT in the Estuary, and its ways of leaving are very slow. The Estuary is said to have a slow *response time* for DDT. Contaminants with slow response times warrant particularly careful management, as if a problem develops, it will probably be around for decades.

trations of diazinon in several samples that exceed a guideline for the protection of aquatic life. Samples causing toxicity to test organisms and having high concentrations of diazinon and chlorpyrifos have also been observed in Guadalupe Slough and Pacheco Slough, two locations in urban watersheds (Daum *et al.* 1999). Other unidentified agents also appear to be contributing to the observed toxicity.

Although selenium is rarely above water guidelines, work outside the RMP indicates that the magnitude of existing contamination in the northern Estuary is sufficient to threaten reproduction in key species within the ecosystem, such as sturgeon, splittail, starry flounder, diving ducks, and dungeness crab (Luoma and Presser 1999).

Cure: Management action

Past experience in the Estuary suggests that it is important to recognize the distinction between persistent (degradation-resistant), sediment-associated contaminants and other contaminants.

It is relatively easy to document the effectiveness of actions to reduce inputs of nonpersistent contaminants. The best historic example of this in the Bay was the implementation of measures to reduce the input of untreated sewage, a nonpersistent contaminant. By 1950, population growth and the discharge of untreated sewage had caused oxygen-depleted conditions to occur in large portions of the Bay (Russell *et al.* 1982). Wastewater treatment began in the 1950s, and by 1980, after the investment of several billion dollars, nearly all of the municipal sewage in the Bay Area received treatment, making oxygen-depleted conditions attributable to municipal wastewater discharges a thing of the past. The effect of actions to reduce nonpersistent contaminants that are currently of concern, such as diazinon, would similarly be obvious and easy to detect.

Persistent, sediment-associated contaminants pose a much thornier problem in San Francisco Bay. As described above, once this type of contaminant is released to the Bay, it enters the sediment. Sediments from many decades are blended together on the bottom of the Bay, and this blended sediment is continually stirred into the water by tidal and wind-driven currents. These processes make the Bay very slow to respond to changes in inputs of persistent, sediment-associated contaminants. Thus, in spite of the significant measures taken long ago to reduce the input of contaminants such as PCBs, DDT, and lead, we have seen little change in their concentrations in Estuary water in the past 20 years. The regional effect of actions to reduce persistent, sediment-associated contaminants will therefore be subtle and difficult to detect over short time spans. The slow response time of the Bay (see *Response time* sidebar) for these chemicals also suggests that managers should be especially cautious in allowing them to enter the Estuary.

Managing contaminant inputs to the water through total maximum daily loads (see *The Clean Water Act and TMDLs* box, page 11) will be one of the most important arenas for management action and Estuary contamination improvement in the future. Guideline exceedances of mercury have led to a regulatory finding of Estuary impairment and the development of a mercury TMDL. In the case of chromium, additional investigation showed that chromium concentrations over guidelines are due to entirely natural processes and cause no adverse effects, so no regulatory action has resulted. Copper and nickel exceedances have led to a finding of Estuary impairment which is currently under review using new information and research. Zinc exceedances have yet to be investigated by regulators. The Estuary has been found impaired due to PCB levels, and plans for a PCB TMDL are underway. Regulatory action for other organic contaminants is also being considered.

Sediment

Status

Sediment contaminant concentrations can vary markedly between sites solely due to differences in sediment characteristics. All else being equal, sediment composed of silt or clay will have higher concentrations than sediment composed of sand. In the Estuary, flow from rivers can change the contaminant levels at a given location by changing the sediment type or by moving contaminated sediments. RMP results have shown changes in sediment contamination levels that occurred after changes in river flow. These relationships should be kept in mind in reviewing the following information.

The condition of Bay sediments can be evaluated by comparisons to sediment quality guidelines. The comparisons made here are based on widely used guidelines (Long *et al.* 1995). 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 Estuary life. Nickel usually exceeds the guideline indicating *probable* harm to Estuary life, although many researchers have low confidence that the current nickel guideline is appropriate, because nickel concentrations in some lands in the region are naturally high, and sediment cores from the Estuary indicate that human activities have not appreciably elevated nickel above the natural background level. Silver, lead and zinc occasionally exceed the guideline for possible harm, and cadmium has never exceeded the guidelines.

Sites in the sloughs and creeks of the South Bay usually had the most guideline exceedances (see *Sediment Quality* figures, page 25). This is probably because they receive the storm drain and wastewater discharge from the largest population center of the Estuary. Many exceedances also occurred at the Alameda and San Pablo Bay locations. The lowest sediment contaminant concentrations and guideline exceedances occurred at sandy sites such as Red Rock and Davis Point. The RMP has never collected a sediment sample that did not have a least one contaminant over guidelines.

Measurements of sediment toxicity found that about 70% of the sediment samples collected by the RMP were toxic to organisms in the laboratory (see *Problem: Sediment is toxic* on page 13).

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

Trends

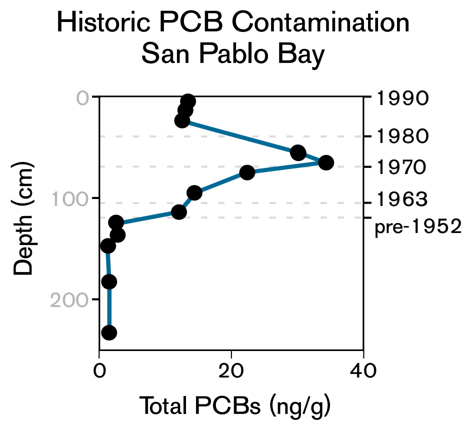
There were few significant Estuary-wide trends in sediment contamination discernible over the last six years. Chromium and nickel appear to be increasing, particularly in the South Bay. Many trends were found at just one or a few locations. At Coyote Creek, several organic contaminants (PCBs, dieldrin, chlordanes, and DDT) and metals (cadmium, chromium, nickel and zinc) appear to be rising (Daum and Thompson, 1999.). Most of the trends at Coyote Creek are not seen at adjacent sites, however. Increases in some contaminant concentrations related to high river flow were seen in 1997 and 1998, such as increases in cadmium, mercury, nickel, and zinc in the South Bay, and DDTs and PAHs in the Sacramento and San Joaquin rivers.

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 (see figure, next page) (Venkatesan *et al.* 1999), probably resulting from wastewater treatment improvements, product bans, and other regulatory actions.

Sources

Most RMP work to date has not directly addressed sources or pathways of sediment contamination (see *Source vs. Pathway,* page 4).

A pattern of increasing contamination as sampling approaches a possible source or pathway usually indicates an actual source or pathway. Results from Coyote Creek



adapted from Venkatesan *et al.* 1999

and Guadalupe River in the South Bay implicate those tributaries as pathways of chlordanes and mercury contamination (Daum *et al.* 1999; see also *New Almaden Mine*, page 9). In San Leandro Bay, contamination patterns suggest adjacent channels conveyed many contaminants to the Bay (Daum *et al.* 1999). Identifying important contaminant pathways will advance progress toward finding sources.

DDTs are found at high levels in sediment throughout the Estuary. This is due to its widespread use prior to its ban in 1972. Additional DDT 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 DDT, but the banning of chlordanes (used 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. 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.

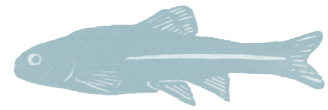
Effects

The RMP has attempted to track actual ecological effects in the Estuary due to sediment contamination by comparing the types and abundances of sediment dwelling (benthic) organisms at different locations (Thompson *et al.* 1999c). Some species of benthic organisms are known to be tolerant of contamination, others are particularly sensitive. A particular composition of organisms can suggest that contamination is having an adverse effect or "impact."

Preliminary examination of more than 500 samples of benthic organisms collected between 1994 and 1997 found that 17% of those samples had evidence of contaminant impacts (Thompson *et al.* 1999c). The remaining samples were designated "reference" samples and considered to be representative of general background Estuary conditions. Applying these findings beyond the RMP, the reference samples were compared to benthic organisms found next to wastewater outfalls and known toxic hot spots (Thompson *et al.* 1999a; Hunt *et al.* 1998). The comparisons indicated that benthic organisms near wastewater outfalls appear unimpacted or only slightly impacted, while organisms in toxic hot spots such as San Leandro Bay are moderately impacted, and those at Stege Marsh in Richmond are severely impacted.

The U.S. Geological Survey (USGS) has also been studying the effects of sediment contamination on benthic organisms. Results indicate the reproductive cycle and condition of the introduced Asian clam *Potamocorbula amurensis,* the most abundant benthic species in the estuarine portions of the Bay, are impaired by exposure to cadmium in sediments in the North Bay (Thompson *et al.* 1996; Parchaso *et al.* 1997). Cadmium has never exceeded guidelines in RMP samples, suggesting that the current cadmium guideline may not be a useful benchmark. USGS studies also showed that even at locations considered "unimpacted," low levels of continual exposure to some metals can cause impaired growth and reproduction. USGS's long-term studies of metals in bivalves near the City of Palo Alto wastewater outfall suggest that even severely impacted locations can recover if the sources of contamination are removed (Hornberger 1999).

A U.S. Environmental Protection Agency study of non-native invasive benthic organisms showed sites with elevated contaminants and impacted benthos had lower proportions of invasive species than unimpacted sites (Lee *et al.* 1999).



The results of sediment toxicity tests (see *Toxicity testing* sidebar, page 6) suggest that the level of contamination of Estuary sediment may be harming some Estuary organisms. See *Sediment is toxic* on page 13 for more details.

Overall assessments of sediment habitat condition are often made by simultaneously evaluating sediment contaminant concentrations, toxicity test results, and benthic organism impacts; this approach is known as the sediment triad. The first sediment triad assessments were made in 1998 and suggest that the habitats of the South Bay and northern Estuary are more impacted than that of the Central Bay.

Cure: Management action

As contamination of the water and the sediment are inextricably linked, action to address water quality problems can also benefit the sediment.

Key past management actions that affected sediment contamination include the banning of organochlorine pesticides and PCBs in the 1970s and 1980s. These actions resulted in a lowering of concentrations of contaminants such as DDT and PCBs from peak levels in the 1970s. Also important are the improvements made to wastewater treatment over the last few decades.

A prerequisite to effective management action is to conclusively determine what contaminants are responsible for sediment toxicity and impacted benthic communities. More work in this area is needed.

Unfortunately, a large part of the cure for sediment contamination problems that are widespread (e.g. DDTs) is time. If inputs have ceased, the sediments will gradually become cleaner. Ensuring that inputs have ceased is a critical role for Estuary management, and one that may be aided by future RMP work directed at source identification.

While there is little to be done about widespread sediment contamination but prevent additional inputs and wait for the sediment concentrations to decline, contamination in small areas may be amenable to direct clean up. Closed military bases deserve special attention as soils and sediments are frequently contaminated; the Regional Water Quality Control Board is overseeing clean up of these sites.

Sediment is dredged from the Estuary to keep navigational channels clear. Disposal of these sediments in marshes and other upland areas has the potential to expand the impact of Estuary sediment contamination, and must be done with caution, as little is known about contamination in this context.

Fish

Status

The fish in the Estuary contain several types of contaminants at levels high enough to raise concern for the health of both humans and wildlife such as harbor seals. The health of the fish themselves may also be affected.

Fish contamination guidelines referred to as "screening values" have been developed for the Estuary by the RMP following the guidance of USEPA. 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 samples tested. 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.

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 striped bass and leopard shark. These differences are due to fish diet, location, metabolism, body composition, and other factors.

The fish from Oakland Harbor contained significantly higher contaminant concentrations than those from other locations.

Trends

Since fish have only been sampled twice by the RMP (1994 and 1997), 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.

Sources

Fish are contaminated mainly by eating contaminated food. Ultimately, water and sediment contamination is the cause of fish contamination. See the *Water* and *Sediment* sections for discussion of water and sediment contaminant sources.

Effects

Concentrations of PCBs in harbor seals and double-crested cormorants in the Estuary appear high enough to impair the health of these animals (Young *et al.* 1998; Davis *et al.* 1997). The source of most of the PCBs in these animals is the consumption of contaminated fish.

No recent studies in the Estuary have looked at the effect of high contaminant concentrations in fish tissue on the health of the fish themselves. Possible effects include impaired reproductive success and abnormal development of early life stages, which tend to be most vulnerable.

No study has ever attempted to link health problems in humans to consumption of Estuary-caught fish. A survey of the consumption of fish and other seafood by Estuary anglers is currently underway, and the results will allow calculation of the range of contaminant intake by Estuary anglers. This in turn can be related to epidemiological data to estimate the health risk anglers face from their consumption practices.

Cure: Management action

The consumption advisory for fish caught in the Estuary issued by the California Office of Environmental Health Hazard Assessment (OEHHA) is intended to protect human health by limiting the consumption of contaminated fish. The advisory is not site-specific, but RMP results indicate that the fish of Oakland Harbor have higher contaminant concentrations than other sites.

Generally speaking, fish contamination levels are managed indirectly through water and sediment contamination reduction efforts. See the *Water* and *Sediment* sections for discussion of related management issues.

Summary of Overall Condition

Some Estuary contaminants are clearly reduced from peak levels seen in earlier decades. Nevertheless, there are several indications that the level of contamination today is high enough to impair the health of the Estuary ecosystem. These indications include the toxicity of water and sediment samples; the frequent presence of contaminant concentrations exceeding water, sediment and fish guidelines; and altered communities of sediment dwelling organisms. As a whole, the Estuary can be described as moderately contaminated. The remedy for this contamination involves both action by Estuary managers to decrease the continuing input of contaminants and undertake sediment clean up actions where appropriate, and the passing of time, to allow the large reservoir of contaminants in the sediment to decrease naturally through permanent burial by new sediment, degradation, and transport to the ocean.

Sites of greatest concern, sites of least concern

Overall, sites in the lower South Bay, the Petaluma River mouth, and San Pablo Bay are the more contaminated than other sites (see figures on pages 24–26). Contamination in the Central Bay is lower primarily due to mixing with relatively clean ocean water. The site west of the Golden Gate is least contaminated.

Contaminants of greatest concern

Of the contaminants measured by the RMP, results suggest that levels of mercury, PCBs, diazinon, and chlorpyrifos are of highest concern. Also of concern are copper, nickel, zinc, DDT, chlordane, dieldrin, dioxins and PAHs. Work outside the RMP suggests that selenium is also of high concern. Of unknown concern are each of the many synthetic organic contaminants that may be in the Estuary but that the RMP does not currently measure.

Future monitoring priorities

There are many changes and additions to RMP monitoring planned or under consideration. Some of the most important are presented here.

- Improve identification and quantification of contaminant sources and pathways
- Improve monitoring of episodic, rainfall-related contamination pulses
- Provide more complete, conclusive identification of the toxic agents responsible for water and sediment toxicity
- Improve monitoring of the adverse ecological effects caused by contaminants
- Begin monitoring for modern, unregulated contaminants that may be the developing problems of the future

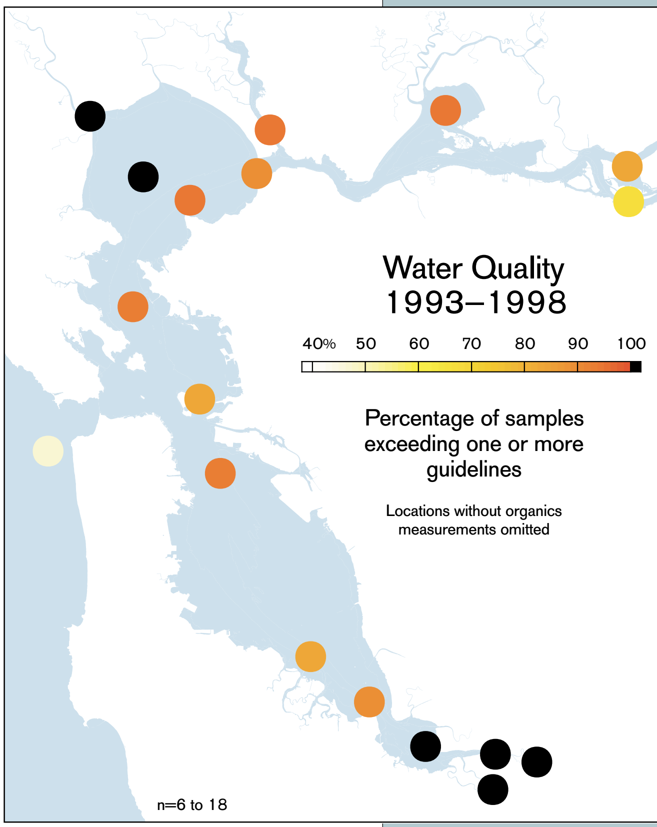
Some possible management actions

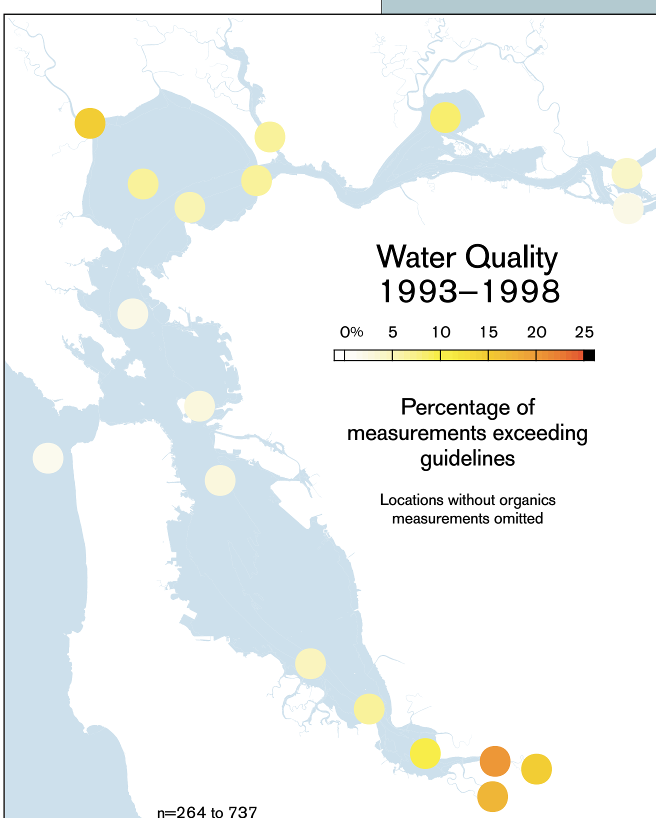
- Reduce remaining inputs of PCBs
- Reduce remaining inputs of mercury
- Once identified, control sources of water toxicity

The 303(d) list

The regulatory agency responsible for water quality in the Estuary, the Regional Water Quality Control Board, makes its own determination of contaminants of concern for the Estuary, based on RMP results and other information. Creation of this list is required by section 303(d) of the Clean Water Act. This is the 1998 list.

- Trace elements:
  - Copper
  - Mercury
  - Nickel
  - Selenium
- Organochlorine pesticides:
  - DDT
  - Chlordane
  - Dieldrin
  - PCBs
- Organophosphate pesticides:
  - Diazinon
- Others:
  - Dioxins
  - Furans
  - Siltation
  - Pathogens
  - Nutrients
  - Invasive species





Water Quality in the Estuary

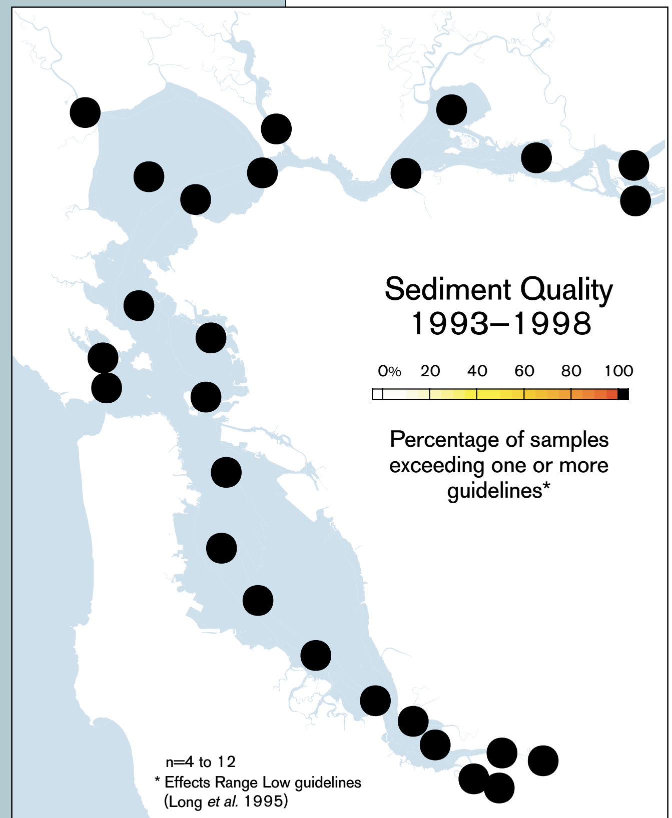
1993–1998

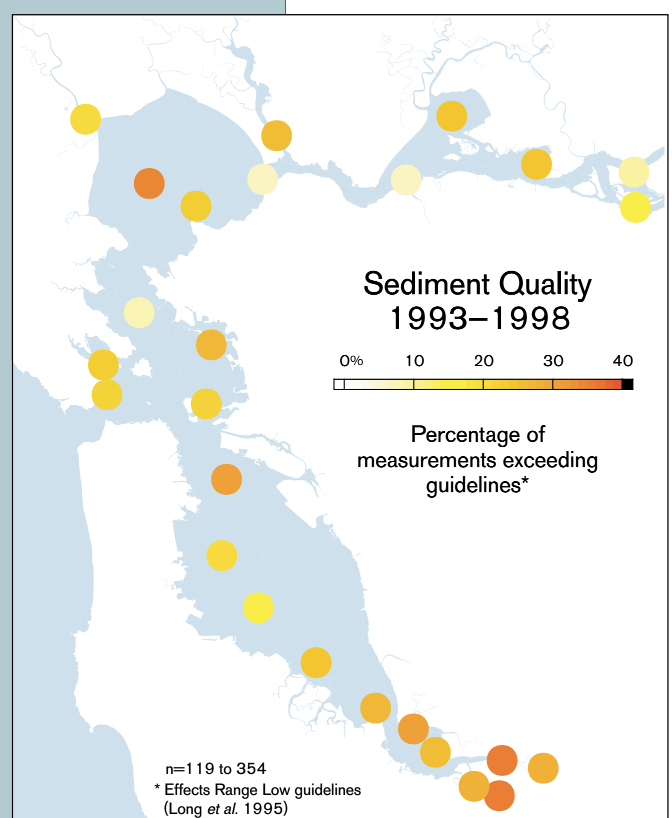
There are many ways of depicting water quality in the Estuary. These illustrations are two ways of looking at overall water quality. The top illustration shows the percentage of RMP samples that had one or more contaminant concentrations over guidelines. This can be thought of as the percentage of "contaminated" samples collected from each site, if we define "uncontaminated" samples as those with no guideline exceedances. The bottom illustration shows the percentage of *measurements* at each site that were over guidelines. For every water sample that is retrieved, many measurements are made: metals, PCBs, DDT, PAHs, etc. About 45 measurements that have guidelines are made on each sample. If a location in the bottom illustration has a value of 25%, for example, this means that on average, water from that location contains about 11 different contaminants over guidelines.

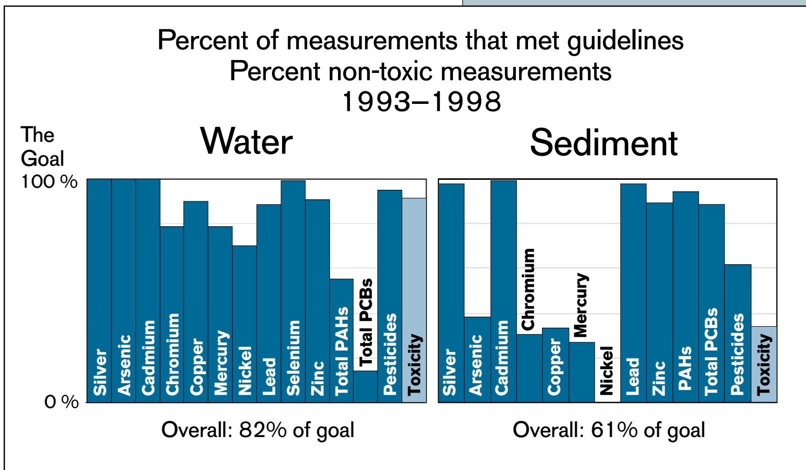
Sediment Quality in the Estuary

1993–1998

There are many ways of depicting sediment quality in the Estuary. These illustrations are two ways of looking at overall sediment quality. The top illustration shows the percentage of RMP samples that had one or more contaminant concentrations over guidelines. This can be thought of as the percentage of "contaminated" samples collected from each site, if we define "uncontaminated" samples as those with no guideline exceedances. The top illustration indicates that the RMP has never collected a sediment sample from the Estuary that was not contaminated. The bottom illustration shows the percentage of *measurements* at each site that were over guidelines. For every sediment sample that is retrieved, many measurements are made: metals, PCBs, DDT, PAHs, etc. About 30 measurements that have guidelines are made on each sample. If a location on the bottom illustration has a value of 25%, for example, that means that, on average, sediment from that location contains about 7 different contaminants over guidelines. Note that comparisons to the nickel guideline, which some researchers think is inappropriately low (see page 19), were included.







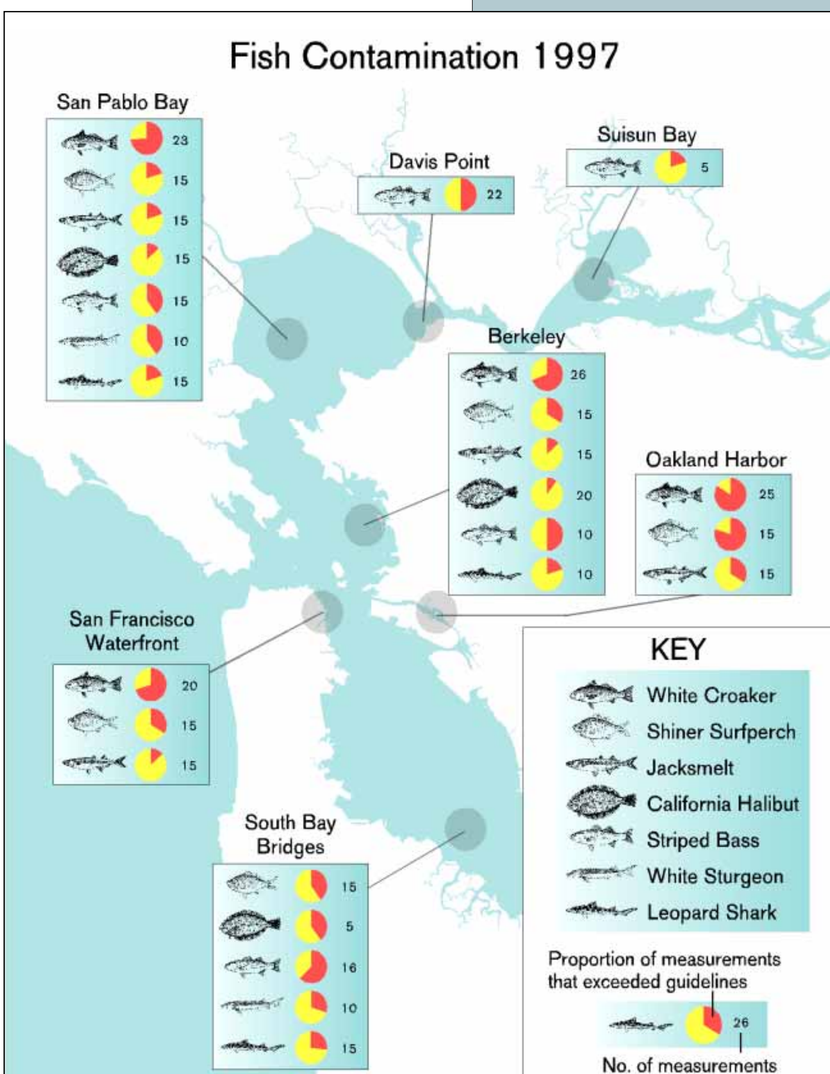
Water and Sediment Quality

1993–1998

Fish Tissue Quality

1997

The top illustration shows the proportion of RMP water and sediment samples that met guidelines (blue bars), and the proportion of samples that were not toxic (light blue bars). Effective management of Estuary contamination should cause each bar to edge closer to the top. Note that some researchers believe the nickel guideline is inappropriately low; see page 19. The bottom illustration shows the proportion of 1997 RMP fish sample measurements that met or exceeded guidelines (screening values). The yellow pie slices indicate the proportion of measurements that met guidelines; more yellow is better.



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.

Benthos

Results of the Benthic Pilot Study, 1994–1997 – Draft Report
I: Macrobenthic Assemblages of the San Francisco Bay-Delta
August 1999

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.
Keywords: sediment, salinity gradient, indicator taxa, amphipods, clams
Available from San Francisco Estuary Institute (510) 231-9539.

Results of the Benthic Pilot Study, 1994–1997 – Draft Report
II: Identifying Benthic Responses to Contamination in San Francisco Bay
September 1999

Authors: Sarah Lowe and Bruce Thompson
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.
Keywords: sediment, indicator taxa, amphipods, oligochaetes, sediment quality triad
Available from San Francisco Estuary Institute (510) 231-9539.

Bioaccumulation

Report of the Bioaccumulation Workshop
October 1999

Prepared by: Bioaccumulation Workgroup
The goal of the workshop was to evaluate the bioaccumulation component of the RMP. This report presents a brief summary of findings and recommendations for program redesign based on the following objectives: determine trends in tissue contamination, measure the bioavailable portion of contaminants in the water column, evaluate which contaminants may be transferred to higher trophic levels of the food web, determine pathways and loadings of contaminants to the Estuary, and determine effects of contaminants in the Estuary.
Keywords: bivalves, bioavailability, trace metals, PCBs, PAHs
URL: http://www.sfei.org/rmp/reports/bivalve_recs/bivalve_recs.html
Available from San Francisco Estuary Institute (510) 231-9539.

The Challenges of Bivalve Bioaccumulation Monitoring in a Highly Variable Environment – Draft Report
Target Availability Date: April 2000

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.
Keywords: contaminants, monitoring, water quality
Available from Applied Marine Sciences (925) 373-7142.

Organic Contaminants

Technical Report of the Chlorinated Hydrocarbon Workgroup
October 1999

Prepared by: Chlorinated Hydrocarbon Workgroup
This report proposes recommendations for a RMP sampling design that optimally meets its objectives with regard to chlorinated hydrocarbons. Discussion on findings and recommendations primarily focus on polychlorinated biphenyls (PCBs). A summary of the mass budget modeling effort used to estimate inputs of PCBs to the Bay and the response time of the Bay for PCBs, and a recommended phased approach to evaluate loadings of contaminants to the Bay from local tributaries are also included.
Keywords: PCBs, response times, sediment, water, bivalves, fish
URL: http://www.sfei.org/rmp/reports/chc_recs/chc_recs.html
Available from San Francisco Estuary Institute (510) 231-9539.

Report of the Pesticide Workgroup
October 1999
Prepared by: Pesticide Workgroup
Findings on the impact of pesticides on the Estuary are presented and used as the basis for recommendations for improving the manner in which the RMP monitors the abundance, distribution, and effects of pesticides in the Estuary. The conceptual models developed by the workgroup for the ecological assessment and restoration with respect to pesticides in the San Francisco Estuary are summarized.
Keywords: contaminants, organophosphates, toxicity identification evaluations (TIE), aquatic toxicity
URL: http://www.sfei.org/rmp/reports/pesticide_recs/pesticide_recs.html
Available from San Francisco Estuary Institute (510) 231-9539.

Resolving Polychlorinated Biphenyl Source Fingerprints in Suspended Particulate Matter of San Francisco Bay
2000
Authors: Glenn W. Johnson, Walter M. Jarman, Corinne E. Bacon, Jay A. Davis, Robert Ehrlich, and Robert W. Risebrough
Multivariate statistical techniques can be used to analyze the patterns, or "fingerprints," of PCB congeners observed in RMP samples and draw conclusions regarding the original Aroclor mixtures that were the sources of the contamination. This article describes such an analysis of RMP water data. Four different Aroclor mixtures were identified in these samples, with varying distributions in space and over time.
Keywords: PCBs, Aroclors, water, PCB fingerprinting
Published in Environmental Science and Technology, Volume 34, Number 4.
Reprints available from Jay Davis at jay@sfei.org.

Estuary Contamination, General

An Overview of Contaminant-Related Issues Identified by Monitoring in San Francisco Bay
1999
Authors: Bruce Thompson, Rainer Hoenicke, Jay A. Davis, and Andrew Gunther
This paper describes the Regional Monitoring Program for Trace Substances (RMP), summarizes several of the major environmental issues identified by the RMP, and provides an assessment of the condition of the Bay in terms of contamination. Several major environmental issues have been identified by the RMP. However, since it does not monitor all ecosystem components, assessments of the overall condition of the Bay cannot be made.
Keywords: assessment, water, sediment, bioaccumulation, toxicity, pesticides, mercury, PCBs
Published in Environmental Monitoring and Assessment, in press.
Reprints available from Bruce Thompson at brucet@sfei.org.

Sediment

Recommendations for Improvement of the RMP Sediment Monitoring
August 1999
Prepared by: Sediment Workgroup
This report summarizes recommendations for the improvement of the sediment monitoring component of the RMP. These recommendations address the following questions: (1) Where should sediment contamination be monitored? (2) How frequently should sediments be monitored? (3) Which sediment variables should be monitored? (4) To what depth should sediment contaminants be measured? (5) Is sediment toxicity testing using *Eohaustorius* and bivalve larvae adequate? (6) Should the RMP initiate a sediment bioaccumulation component? (7) Should benthic macrofauna be monitored?
Keywords: contamination, benthic macrofauna, bivalves, transport and fate model
URL: http://www.sfei.org/rmp/reports/sediment_recs/sediment_recs.html
Available from San Francisco Estuary Institute (510) 231-9539.

Relationships Between Sediment Contamination and Toxicity in San Francisco Bay
1999
Authors: Bruce Thompson, Brian Anderson, John Hunt, Karen Taberski, and Bryn Phillips
The purpose of this study is to determine the relationships between sediment contamination and toxicity in San Francisco Bay, and identify contaminants that are statistically associated with the observed toxicity. These analyses are an important step in developing understanding about which sediment components may be contributing to toxicity in the Bay. Results from monitoring conducted between 1991 and 1996 show that sediment contamination patterns are different in the major segments of the Bay and at each site, and that several contaminants at most sites are consistently above sediment quality guidelines associated with toxicity.
Keywords: amphipods, bivalve embryos, contaminants, sediment bioassays
URL: http://www.sfei.org/rmp/reports/relationships.html
Published in Marine Environmental Research 48. Reprints available from Bruce Thompson at brucet@sfei.org.

Investigation of Chemicals Associated With Amphipod Mortalities at Two Regional Monitoring Program Stations – Draft Report
January 2000
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.
Keywords: sediment, toxicity, pore water, organic chemicals, toxicity identification evaluations (TIE)
Available from San Francisco Estuary Institute (510) 231-9539.

Sediment Conditions Near Wastewater Discharges in San Francisco Bay: Results of the Bay Area Dischargers Association's Local Effects Monitoring Program, 1994–1997
July 1999

Authors: Bruce Thompson, Sarah Lowe, and Lauren Gravitz

The Bay Area Dischargers Association's (BADA) Local Effects Monitoring Program (LEMP) and the RMP Benthic Pilot Study, which also began in 1994, both address the need to determine the condition of resident biota in order to evaluate whether or not ecological effects from contamination occur in the Estuary. This report analyzes and interprets sediment data collected by the BADA LEMP between 1994 and 1997.

Keywords: benthic macrofauna, contamination, toxicity, bioaccumulation, bivalves

Available from San Francisco Estuary Institute (510) 231-9539.

Atlas of Sediment Contamination, Toxicity, and Benthic Assemblages in San Francisco Bay – Draft Report
August 1999

Authors: Bruce Thompson and Ted Daum

The Sediment Atlas was created because of the need for a summary of information about sediments in San Francisco Bay. The management of sediments in the Bay requires access to such information for many purposes, including dredged sediment management, toxic hot-spot identification, military base clean up and restoration, and biological resource management. It is also necessary to summarize sediment status and trends in order to determine how to improve regional monitoring efforts.

Keywords: trace metals, PCBs, PAHs, pesticides, transport and fate model

Available from San Francisco Estuary Institute (510) 231-9539.

Investigations of Sediment Elutriate Toxicity at Three Estuarine Stations in the San Francisco Bay, California – Draft Report
January 2000

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.

Keywords: bivalves, amphipods, trace metals, copper, contaminants

Available from San Francisco Estuary Institute (510) 231-9539.

Sources, Pathways, and Loadings

San Francisco Bay Atmospheric Deposition Pilot Study, 1999 Interim Progress Report
February 2000

Authors: Pam Tsai, Rainer Hoenicke, and Eric Hansen

The deposition of air pollutants to surface water can occur by several processes, including rain or snow scavenging of gases and particles, dry deposition of dust and particles, deposition through cloud and fog water, air-water exchange, and air-terrestrial exchange processes. The objective of this Pilot Study is to obtain seasonal and annual estimates of the deposition of selected pollutants from the air directly to the surface of San Francisco Bay. This report presents a synopsis of the study, its progress to-date, and some preliminary results.

Keywords: cadmium, chromium, copper, mercury, nickel, dry deposition, wet deposition

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

Available from San Francisco Estuary Institute (510) 231-9539.

Draft Technical Report of the Sources, Pathways, and Loadings Workgroup
September 1999

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.

Keywords: PCBs, PAHs, pesticides, mercury, selenium, copper, nickel, silver, cadmium, atmospheric deposition

Available from San Francisco Estuary Institute (510) 231-9539.

Estuary Interface Pilot Study Progress Report
Target Availability Date: April 2000

Authors: Ted Daum 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 contributions to the Estuary of pollutant inputs from adjacent watersheds by sampling at the interface between the Bay and upland. 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.

Keywords: water, sediment, metals, organics, contaminants, PCB fingerprint

Available from San Francisco Estuary Institute (510) 231-9539.

Water

Cyanobacterial Populations in San Francisco Bay
November 1999

Authors: Brian Palenik and A. Russ Flegal
This study utilizes the flow cytometer to detect cyanobacteria in the San Francisco Bay and analyzes the spatial and temporal variation of cyanobacterial populations. Due to their rapid analysis in samples, cyanobacteria may be useful as an indicator species for water quality monitoring and metal-impacted environments.
Keywords: phytoplankton, copper, toxicity, monitoring
URL: http://www.sfei.org/rmp/reports/cyanobacterial/cyanobacterial.html
Available from San Francisco Estuary Institute (510) 231-9539.

Patterns of Water-Quality Variability in San Francisco Bay During the First Six Years of the RMP, 1993–1998
1999

Authors: James E. Cloern, Brian E. Cole, Jody L. Edmunds, Tara S. Schraga, and Andrew Arnsberg
The U.S. Geological Survey (USGS) contributes to the RMP by measuring the spatial variability of basic water-quality constituents along the entire San Francisco Bay system. Results from the first six years of the RMP are used to identify the mean spatial patterns along the Estuary, and to show the deviations around the mean patterns caused by interannual, seasonal, and episodic changes in the climate system. These primary patterns of spatial and temporal variability provide a foundation for interpreting and understanding the patterns of variability in the other constituents measured within the RMP.
Keywords: salinity, suspended solids, chlorophyll *a*, dissolved oxygen, bioavailability, phytoplankton
URL: http://www.sfei.org/rmp/reports/wqpatterns/patterns.html
Available from San Francisco Estuary Institute (510) 231-9539.

Time Series of Suspended-Solids Concentration, Salinity, Temperature, and Total Mercury Concentration in San Francisco Bay During Water Year 1998
1999

Authors: Catherine A. Ruhl and David H. Schoellhamer
Many physical processes and their associated time scales affect how constituents within the San Francisco Bay vary. Continuous time series of data on basic state variables of the Bay provide insight on the effect and relative importance of physical processes on the Bay. This article describes qualitatively time series of suspended-solids concentration (SSC), salinity, water temperature, and mercury during the water year 1998. Calculated time series of total mercury concentration and other trace element concentrations linearly correlated with SSC can be used to evaluate water quality objectives that are based on averaging periods much longer than the time required to sample.
Keywords: sediment, time series data, mercury, phytoplankton
Available from San Francisco Estuary Institute (510) 231-9539.

Acknowledgments

Thanks to all those who provided feedback on this first edition of *The Pulse*, including Khalil Abu-Saba, Brian Anderson, Brock Bernstein, Ted Daum, Jack Gregg, Cristina Grosso, Ellen Johnck, Kathy Kramer, Sarah Lowe, Alan Mearns, Trish Mulvey, Fred Nichols, Ariel Okamoto, Bryn Phillips, Bernadette Powell, Morgan Rogers, Linda Spencer, Karen Taberski, Pam Tsai, Sheila Tucker, and Donald Yee. We received many thoughtful suggestions, corrections, additions, and ideas for future editions.

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References

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.

Carter, B. U.S. Environmental Protection Agency. Personal communication.

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. San Francisco Estuary Institute. Program Director of the Regional Wetlands Monitoring Program. Personal communication.

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.

Daum, T. and B. Thompson. 1999. Atlas of sediment contamination, toxicity, and benthic assemblages. Draft Report. San Francisco Estuary Institute, Richmond, CA.

Daum, T., R. Hoenicke, and L. Gravitz. 1999. Estuary Interface Pilot Study. *In* 1997 Annual Report: San Francisco Estuary Regional Monitoring Program. 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.

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.

Hunt, J.W., B.S. Anderson, B.M. Phillips, J. Newman, R.S. Tjeerdema, K. Taberski, C.J. Wilson, M. Stephenson, H.M. Puckett, R. Fairey, and J. Oakden. 1998. Sediment quality and biological effects in San Francisco Bay: Bay Protection and Toxic Cleanup Program Final Technical Report. California State Water Resources Control Board, Sacramento, CA.

Hunt, J., B. Anderson, B. Phillips, and K. Taberski. 1999. Bay Protection and Toxic Cleanup Program: studies to identify toxic hot spots in the San Francisco Bay region. *In* 1997 Annual Report: San Francisco Estuary Regional Monitoring Program for Trace Substances. San Francisco Estuary Institute, Richmond, CA.

Lee, H., B. Thompson, and S. Lowe. 1999. Impacts of nonindigenous species of subtidal benthic assemblages in the San Francisco Estuary. Draft Report. San Francisco Estuary Institute, Richmond, CA.

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.

Luoma, S. and T. Presser. 1999. Implications Of Selenium Contamination For Ecosystem Restoration Activities In The San Francisco Bay-Delta And Watershed: A CalFED "White Paper." U.S. Geological Survey, Menlo Park, CA.

Obrebski, S., J. Orsi and W. Kimmerer. 1992. Long-term trends in zooplankton distribution and abundance in the Sacramento-San Joaquin Estuary. Interagency Ecological Program Technical Report #32.

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.

Parchaso, F., C.L. Brown, J.K. Thompson, and S.N. Luoma. 1997. In situ effects of trace contaminants on the ecosystem in the San Francisco Bay Estuary, 1995: the necessary link to establishing water quality standards II. U.S. Geological Survey Open File Report 97-420.

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.

Phillips, D.J.H. 1988. Monitoring of toxic contaminants in the San Francisco Bay-Delta: a critical review emphasizing spatial and temporal trend monitoring. Aquatic Habitat Institute, Richmond, CA (now the San Francisco Estuary Institute).

Russel, P.P., T.A. Bursztynsky, L.A. Jackson, and E.Y. Leong. 1982. Water and waste inputs to San Francisco Estuary – an historical perspective. *In* Kockelman, W.J., T.J. Conomos, and A.E. Leviton (eds.), San Francisco Bay: use and protection. pp. 127-136. Pacific Division, American Association for the Advancement of Science, San Francisco, CA.

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

SFEI. 1998b. Regional Monitoring Program for Trace Substances. 1998 Quality Assurance Program Plan. San Francisco Estuary Institute, Richmond, CA.

SFEI. 1999a. 1997 Annual Report: San Francisco Estuary Regional Monitoring Program for Trace Substances. San Francisco Estuary Institute, Richmond, CA.

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

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

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

SFEI. 1999e. 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)

SFEP. 1992. A report on conditions and problems in the San Francisco Bay/ Sacramento-San Joaquin Delta Estuary. San Francisco Estuary Project, Oakland, CA.

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.

Thompson, B., S. Lowe, and L. Gravitz. 1999a. Sediment conditions near wastewater discharges in San Francisco Bay: Results of the Bay Area Discharger's Association's Local Effects Monitoring Program, 1994-1997. San Francisco Estuary Institute, Richmond, CA.

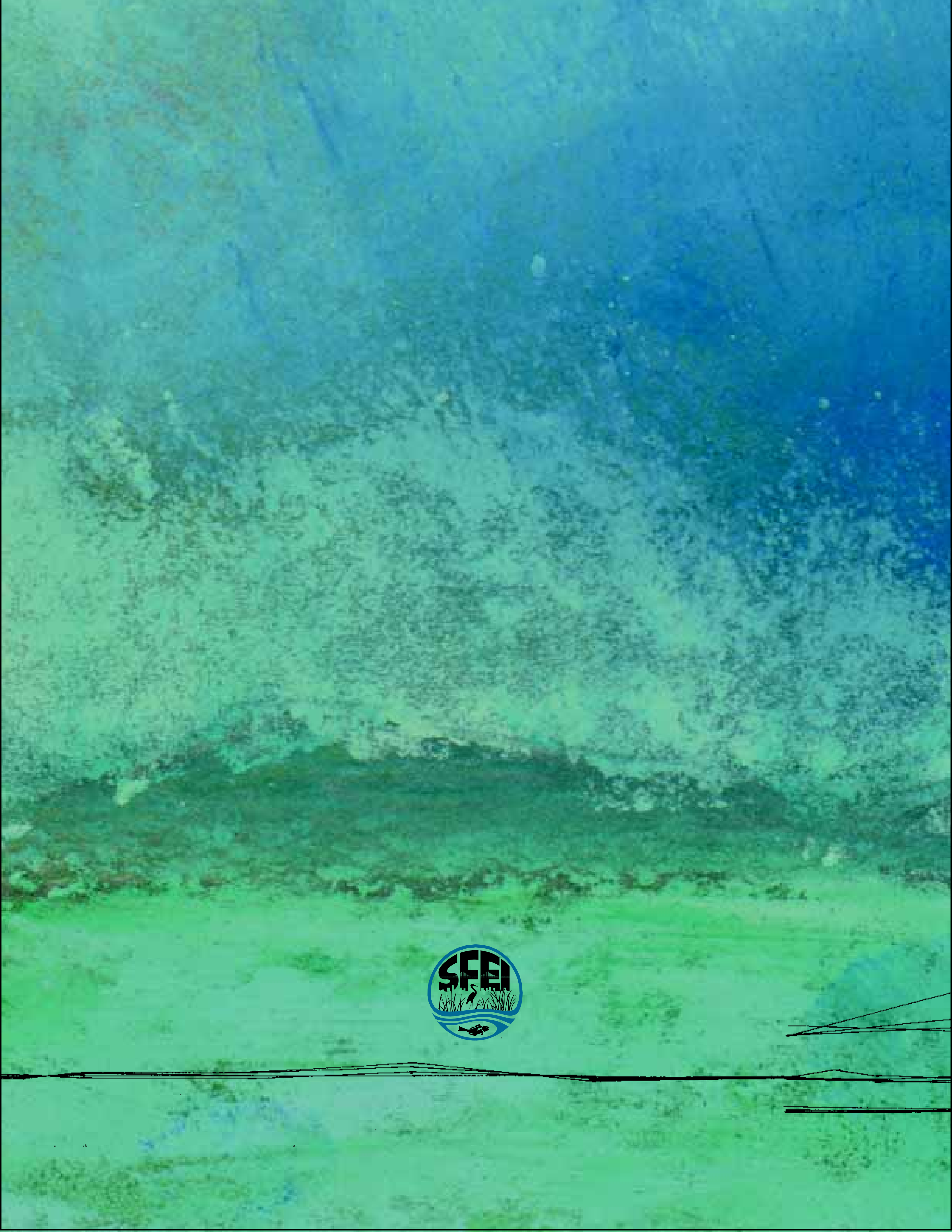
Thompson, B., B. Anderson, J. Hunt, K. Taberski, and B. Phillips. 1999b. Relationships between sediment contamination and toxicity in San Francisco Bay. Marine Env. Research 48:285-309.

Thompson, B., S. Lowe, H. Peterson, and M. Kellogg. 1999c. Results of the Benthic Pilot Study, 1994-1997. II: Identifying Benthic Responses to Contamination in San Francisco Bay. Draft Report. San Francisco Estuary Institute, Richmond, CA.

Thompson, J.K., F. Parchaso, C.L. Brown, and S.N. Luoma. 1996. In situ ecosystem effects of trace contaminants in the San Francisco Bay Estuary: The necessary link to establishing water quality standards. U.S. Geological Survey Open File Report 96-437.

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.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