

THE STATE OF SAN FRANCISCO BAY: WATER QUALITY

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ABSTRACT

The mission of the Regional Monitoring Program for Water Quality in the San Francisco Estuary (RMP) is to provide the information needed by policy makers, water quality managers, and the public to make decisions about stewardship of this magnificent ecosystem. The RMP and other programs collect a wealth of information on the soup of chemicals that pervades the waters of the Bay, their sources and transport pathways, their cycling within the ecosystem, and the health threats they pose to wildlife and humans. To be useful to policy makers and the public, this complex mass of data must be boiled down to simple and clear statements about the condition of the Bay. Drawing on information summarized in a recent series of synthesis articles on contamination in the Bay, a concise and simple summary has been developed that retains enough detail to be an accurate reflection of reality, yet is intended to be readily understood by all through a visual representation. Methylmercury, PCBs, dioxins, and exotic species are the currently regulated pollutants that pose the most severe problems in the Bay. Recovery in a 20-year timeframe is possible for methylmercury (though further deterioration is also possible), slight recovery is anticipated for PCBs, and recovery for dioxins and exotic species is not expected in this timeframe. Significant concerns also exist for selenium, PAHs, and legacy pesticides (dieldrin, DDT), though the degree of present impairment is not clear. Nickel, copper, and nutrients are below thresholds, but merit continued tracking. Emerging concerns that are currently not specifically regulated but appear to pose significant risks include PBDEs, pyrethroids, and sediment toxicity. The combined effect of pollutant mixtures is also a continuing concern. Urban runoff is an important pathway for many of the pollutants of concern. River inflow, remobilization from sediment, and wastewater discharges are also important for multiple pollutants. The Lower South Bay is particularly impacted by many pollutants. Important information gaps include sources of methylmercury, selenium fate and transport, and sources of sediment toxicity.

KEYWORDS

methylmercury, PCBs, dioxins, exotic species, DDT, dieldrin, PBDEs, selenium, pyrethroids

HOW IS THE BAY DOING?

The mission of the Regional Monitoring Program for Water Quality in the San Francisco Estuary (RMP) is to provide the information needed by policy makers, water quality managers, and the public to make decisions about stewardship of this magnificent ecosystem. The RMP and other programs collect a wealth of information on the alphabet soup of chemicals that pervades the

waters of the Bay, their sources and pathways of entry, their cycling within the ecosystem, and the health threats they pose to wildlife and humans. To be useful to policy makers and the public, this complex mass of data must be boiled down to brief and understandable statements about the condition of the Bay. People need as simple an answer as possible to the question: “How is the Bay doing?”

The state of water quality in the Bay cannot be accurately summarized in a single score, grade, word, phrase, or sentence. The complex mixture of substances in Bay waters includes pollutants that vary in the severity of the problem they pose, their origins, their geographic distribution, and their trajectories of improvement or deterioration. It is possible, however, to present this information in a concise and simple summary that retains enough detail to be an accurate reflection of reality, while being readily understood by all.

In the past three years the RMP and the Clean Estuary Partnership (CEP) have sponsored technical reviews of the state of knowledge of many pollutants of concern in the Bay. The reviews have been published in the form of Conceptual Model and Impairment Assessment Reports by the CEP and as articles in a special issue of the journal *Environmental Research* by RMP investigators and collaborators. These reviews were able to draw on the rich datasets created by the RMP, the U.S. Geological Survey, and other programs that make the Bay one of the most, perhaps the most, thoroughly monitored estuaries in the world (Sañudo-Wilhelmy et al. 2004).

This article provides a brief, nontechnical summary of the information compiled in the 7 CEP reports and the 11 journal articles, which in turn summarized hundreds of other reports and thousands and thousands of water quality data points. Having this information in hand affords an excellent opportunity to provide an assessment of the current state of water quality in the Bay.

BAY WATER QUALITY AT A GLANCE

Tables 1 - 5 provide a pictorial summary of the current state of knowledge for the pollutants of primary concern in San Francisco Bay. For each pollutant, information for six subject areas is summarized: the severity of the problem (“Status”), the nature of the risks to humans and wildlife health (“Health Risks”), where the pollutant is coming from (“Important Pathways”), areas that are particularly polluted (“Spatial Pattern”), trends in recent decades (“Recovery Trend”), and what is expected for the future based on existing information (“Likely Status in 20 Years”). These six areas correspond to the major topics that the RMP is designed to study (Hoenicke 2005).

Problems Solved

Bay water quality has improved dramatically since the passage of the Clean Water Act in 1972. Prior to 1972, severe dissolved oxygen depletion due to inputs of organic waste and nutrients was a common occurrence, causing fish kills, foul odors, and other water quality problems. The Clean Water Act provided clear goals and over a billion dollars for construction of Bay Area wastewater treatment facilities, resulting in improved wastewater treatment that sharply reduced the loading of organic waste, nutrients, and other pollutants. Other important management

Legend for Tables 1 - 5

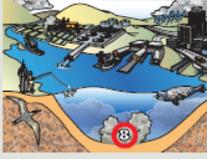
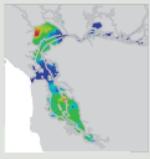
Regulatory Status: Corresponds to 303(d) List Status	
	The entire Bay is on the 303(d) List, and concentrations are much higher than existing water quality objectives or thresholds for concern
	The entire Bay is on the 303(d) List, and concentrations are slightly above existing water quality objectives or thresholds for concern
	Portions of the Bay are on the 303(d) List, and concentrations are near existing water quality objectives or thresholds for concern
	Not included on the 303(d) List, and concentrations are below existing water quality objectives or thresholds for concern
	Water quality objectives do not exist, so not included on the 303(d) List, but concern does exist for water quality impacts

Recovery Trend: Describes long-term trends towards recovery in recent decades	
	Significant improvement in recent decades
	Slow improvement in recent decades
	No improvement or deterioration in recent decades
	Slow deterioration in recent decades
	Significant deterioration in recent decades

Health Risks	
	Primary driver of fish consumption advisory
	Secondary driver of fish consumption advisory
	Primary driver of duck consumption advisory
	Human health threshold under development by USEPA
<p>Significant risk to wildlife. Species shown indicates those considered at greatest risk for each pollutant based on existing information.</p> <div style="display: flex; justify-content: space-around; align-items: flex-start;"> <div style="text-align: center;"> Clapper Rail</div> <div style="text-align: center;"> Delta Smelt</div> <div style="text-align: center;"> Splittail</div> <div style="text-align: center;"> Striped Bass Larva</div> <div style="text-align: center;"> Pacific Herring Larva</div> <div style="text-align: center;"> Forster's Tern</div> </div> <div style="display: flex; justify-content: space-around; align-items: flex-start; margin-top: 10px;"> <div style="text-align: center;"> Harbor Seal</div> <div style="text-align: center;"> Mussel Larva</div> <div style="text-align: center;"> Amphipod</div> </div>	



Table 1 – Water Quality in San Francisco Bay: Problems Solved

Pollutant	Status	Health Risks	Important Pathways	Spatial Pattern	Recovery Trend	Likely Status in 20 Years
Organic Waste (oxygen depletion)		Effects not likely				
Nutrients		Effects not likely				
Silver		Effects not likely				

Spatial patterns shown for dissolved oxygen in water, nitrate and nitrite in water, and silver in water.

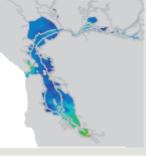
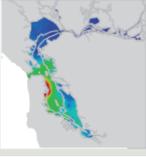
Table 2 – Water Quality in San Francisco Bay: The Biggest Water Quality Problems

Pollutant	Status	Health Risks		Important Pathways	Spatial Pattern	Recovery Trend	Likely Status in 20 Years
		Humans	Wildlife				
Total Mercury							
Methylmercury							
PCBs							
Dioxins							
Exotic Species		Major impacts on virtually all types of invertebrates and some fish; possible impacts on some birds. So far only minor human health problems.		Ship ballast water Ship and boat hull fouling Bait imports and transfers	Except near the mouth of the Bay, common and dominant on hard and soft substrates and common in the water column.		

Spatial patterns shown for total mercury in sediment, methylmercury in sediment, and PCBs in sediment.

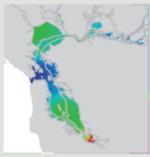
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Table 3 – Water Quality in San Francisco Bay: Other Threats

Pollutant	Status	Health Risks		Important Pathways	Spatial Pattern	Recovery Trend	Likely Status in 20 Years
		Humans	Wildlife				
Selenium							
Legacy Pesticides (DDT, dieldrin, and chlordane)							
PAHs							

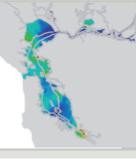
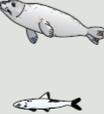
Spatial patterns shown for total selenium in water, DDT in sediment, and PAHs in sediment.

Table 4 – Water Quality in San Francisco Bay: Below Thresholds But Carefully Watched

Pollutant	Status	Health Risks		Important Pathways	Spatial Pattern	Recovery Trend	Likely Status in 20 Years
		Humans	Wildlife				
Nickel		Effects not likely					
Copper							

Spatial patterns shown for dissolved nickel in water and dissolved copper in water.

Table 5 – Water Quality in San Francisco Bay: Rising Concerns

Pollutant	Status	Health Risks		Important Pathways	Spatial Pattern	Recovery Trend	Likely Status in 20 Years
		Humans	Wildlife				
PBDEs							
Pyrethroids					insufficient data		
Sediment Toxicity							
Pollutant Mixtures							

Spatial patterns shown for BDE 47 in sediment and toxicity to two test organisms (green shaded semicircles indicate significant toxicity to one of the species) in samples from 2006.

actions in the 1970s and 1980s included bans on many pollutants, including PCBs, DDT, dieldrin, and chlordane. Significant changes in industrial and military activity also occurred over the past few decades, including the closing of many military facilities and polluting industries (notable examples are a lead smelter and a photo processing plant), and the cessation of mining activity.

As a result of these actions and changes, the most serious water quality problems that were recognized in the 1970s have largely been solved (Table 1). RMP monitoring has documented a general trend of steadily increasing dissolved oxygen and elimination of low-oxygen conditions in response to reduced inputs of organic waste and nutrients over the past few decades (Cloern et al. 2003). Fish kills are no longer a common occurrence in the Bay. Toxic pollutants have also generally declined since the period of peak contamination in the 1950s and 1960s (van Geen and Luoma 1999), and some have fallen to concentrations that are considered not to pose significant health risks to humans or aquatic life. For example, in the 1970s the Bay had the highest silver concentrations recorded for any estuary in the world, but the closure of a major photo processing plant and improved wastewater treatment led to a reduction in concentrations in South Bay clams from 100 ppm in the late 1970s to 3 ppm in 2003, eliminating adverse impacts on clam reproduction.

Concerns about these problems have not been entirely eliminated. Recent increases in the growth of algae in the Bay suggest that impacts could occur if nutrient loading to the Bay escalates. Low dissolved oxygen resulting indirectly from the large amount of freshwater input to the Bay in 2006 was considered a possible cause of a fish kill in June of that year. Dissolved oxygen and nutrient concerns still exist for salt ponds, lagoons, and other areas around the edges of the Bay. However, with the continued vigilance of regulators and treatment plant operators, broad-scale adverse impacts of dissolved oxygen, nutrients, and silver on Bay water quality are not likely.

The Bay's "Most Wanted"

Water quality managers maintain an official list of the pollutants that are considered to be causing unacceptable adverse impacts on the Bay. This list is known as the "303(d) List", because development of the list is a requirement of Section 303(d) of the Clean Water Act. The status for each pollutant shown in Tables 1 - 5 is derived from the most recent version of the 303(d) List.

Four pollutants – mercury (total mercury and methylmercury), PCBs, dioxins, and exotic species – are classified as having the most severe impacts on Bay water quality because the entire Bay is considered impaired by these pollutants, and the degree of impairment is well above established thresholds of concern.

Mercury is Bay water quality enemy number one. Mercury is a primary driver of the fish consumption advisory for the Bay, and also is suspected to be adversely affecting wildlife populations, including the endangered California Clapper Rail. Due to these concerns, the first TMDL for the Bay has been developed for mercury. Mercury has two entries in Table 2, total mercury and methylmercury, because these two different forms present very different opportunities for management.

Total mercury is the sum of all of the different forms of mercury in the environment. Total mercury is easy to monitor, and its sources, distribution, and trends are relatively well understood. Total mercury is persistent, is largely bound to sediment particles that are efficiently trapped within the Bay, and is distributed so widely throughout the Bay-Delta and its watershed that it will take many decades for total mercury concentrations to decline significantly.

Methylmercury typically represents about 1% of total mercury, but is the form that accumulates in aquatic life and poses health risks to humans and wildlife. Methylmercury is a neurotoxicant, and is particularly hazardous for fetuses and children and early life-stages of wildlife species as their nervous systems develop. In contrast to total mercury, methylmercury is not persistent, and its concentrations are highly variable over small intervals of time and space and do not closely correspond with total mercury concentrations. The sources of methylmercury in the Bay, particularly the methylmercury that actually gets taken up into the food web, are not well understood. Methylmercury concentrations in the Estuary (as indicated by accumulation in striped bass) have been relatively constant since the early 1970s, but could quite plausibly increase, remain constant, or decrease in the next 20 years. Wetlands are often sites of methylmercury production, and restoration of wetlands in the Bay on a grand scale is now beginning, raising concern that methylmercury concentrations could increase across major portions of the Bay. However, methylmercury cycling is not yet well understood, and recent findings suggest that some wetlands actually trap methylmercury and remove it from circulation. Consequently, with improved understanding of methylmercury dynamics in the Bay, approaches might be found that would prevent increases in methylmercury concentrations, or possibly even reduce concentrations and associated health risks in the next 20 years.

Other pollutants on the most wanted list are PCBs, dioxins, and exotic species. Like total mercury, PCBs are highly persistent, bound to sediment particles, and widely distributed throughout the Bay and its watershed. PCBs reach high concentrations in humans and wildlife at the top of the food chain where they can cause developmental abnormalities and growth suppression, endocrine disruption, impairment of immune system function, and cancer. PCB concentrations in sport fish are more than 10 times higher than thresholds of concern for human health and are, along with mercury, a primary driver of the fish consumption advisory for the Bay. There is also concern for the effects of PCBs on wildlife, including species like harbor seals at the top of the Bay food web and sensitive organisms such as young fish. General recovery of the Bay from PCB contamination is likely to take many decades because the rate of decline is slow and concentrations are so far above the threshold for concern. One bright spot is Suisun Bay, where present concentrations are not as high and should be below the threshold in 20 years.

The human and wildlife health risks of dioxins are similar to those for PCBs. Dioxins have not received as much attention from water quality managers because there are no large individual sources in the Bay Area and concentrations in the Bay are among the lowest measured across the U.S. Nevertheless, concentrations in sport fish are well above the threshold for concern and the entire Bay is included on the 303(d) List. Dioxins are similar to PCBs in their persistence and distribution throughout the Bay and its watershed, and are unlikely to decline significantly in the next 20 years.

Exotic species represent a different form of pollution that is included on the 303(d) List. San Francisco Bay is considered the most highly invaded estuary in the world. Nonnative species introduced to the Bay have reduced or eliminated populations of many native species (so that in some regions and habitats virtually 100% of the organisms are introduced), disrupted food webs, eroded marshes, and interfered with fishing, boating, and water contact recreation. Recently adopted state ballast discharge regulations to be phased in over 2009-2016, if rigorously implemented and enforced, would essentially resolve one major pathway for exotic species.

Other Pollutants of Concern

Three pollutants – selenium, legacy pesticides (currently banned pesticides that were used in the past and still persist in the environment, including the insecticides DDT, dieldrin, and chlordane), and PAHs – are also of concern, because either the entire Bay or several Bay locations are included on the 303(d) List and concentrations are above established thresholds of concern.

Selenium accumulates in Bay diving ducks to concentrations that pose a potential health risk to humans who eat them, and have caused a consumption advisory for ducks to be issued. Selenium concentrations also pose a threat to wildlife in the Bay. Recent studies suggest that selenium concentrations may be high enough to cause deformities, growth impairment, and mortality in early life-stages of Bay fish species. The major pathways of selenium input into the Bay are outflow from the Delta and industrial and municipal wastewater effluent. While the amount of selenium discharged by Bay Area refineries has been reduced significantly in the past 15 years, concentrations in the Bay do not show an increasing or decreasing trend. A TMDL for selenium is in the planning stages. The future status of the Bay with respect to selenium is unclear primarily due to uncertainty regarding the management of selenium-laden agricultural runoff from the San Joaquin Valley, which has a very large influence on selenium concentrations in the north Bay.

The entire Bay is on the 303(d) List for legacy pesticide contamination. Legacy pesticides were one of the drivers of the fish consumption advisory issued in the early 1990s. Concentrations in the Bay have been slowly but steadily falling since these chemicals were banned in the 1970s and 1980s. In recent sampling, very few sport fish samples have exceeded thresholds of concern for these chemicals. Given the observed pattern of decline, in 20 years it is likely that no sport fish will exceed thresholds.

PAHs (polycyclic aromatic hydrocarbons) are included on the 303(d) List for several Bay locations. There is also concern that PAH concentrations in sediment across much of the Bay exceed a threshold for potential impacts on early life stages of fish. PAH concentrations over the past 20 years have held fairly constant. Increasing population and motor vehicle use in the Bay Area are cause for concern that PAH concentrations could increase over the next 20 years. On the other hand, PAH concentrations in Bay Area air have declined over the past ten years, and if PAH inputs to the Bay can be decreased concentrations are expected to drop quickly.

Below Thresholds But Carefully Watched

Two heavy metals – nickel and copper – are below thresholds of concern in the Bay. These metals have received a great deal of attention from water quality managers. In the 1990s copper and nickel were major concerns in the Bay, as concentrations were frequently above the water quality objectives in effect at that time. An evaluation of the issue by the Water Board and stakeholders led to new water quality objectives for copper and nickel in the Lower South Bay which are less stringent but still considered fully protective of aquatic life, and the removal of copper from the 303(d) List in 2002. Portions of the Bay (including the Petaluma River, San Pablo Bay, and Suisun Bay) remained on the 2006 303(d) List for nickel, but this was based on comparison with the now superseded old Basin Plan objective for total nickel. Along with the new objectives for Lower South Bay, a program has been established to guard against future increases in concentrations in the Bay. The program includes actions to control known sources in wastewater, urban runoff, and use of copper in shoreline lagoons and on boats. More aggressive actions to control sources can be triggered by increases in copper or nickel concentrations.

Rising Concerns

PBDEs, pyrethroids, sediment toxicity, and pollutant mixtures are classified as rising concerns because while water quality objectives have not yet been established for these pollutants in order to place them on the 303(d) List, there is a significant amount of concern about their impacts on the Bay. PBDEs (polybrominated diphenyl ethers), a class of bromine-containing flame retardants that was practically unheard of in the early 1990s, increased rapidly during that decade and are now ubiquitous in the Bay. Concentrations of PBDEs in humans and wildlife in the Bay Area are among the highest that have been reported in the world. The body of evidence on the toxic effects of PBDEs is growing. USEPA is expected to establish a threshold for concern for PBDEs soon, and this would provide a basis for evaluating the need for fish consumption advice and 303(d) listing. The California Legislature banned the use of two types of PBDE mixtures in 2006. A third major type of PBDE, known as “deca”, is still commercially produced. PBDEs are persistent, but appear to be less so than PCBs, so concentrations would be expected to decline once releases to the environment are reduced. Tracking the trends in these chemicals will be extremely important to determine the rate of decline as a result of the ban and if further management actions are necessary to accelerate recovery.

Pyrethroid insecticide use in agriculture, pest control around homes and other buildings, and backyard applications has increased in recent years as the use of organophosphate pesticides has declined. Fish and aquatic invertebrates are quite sensitive to pyrethroids, raising concern for possible impacts on non-target species in aquatic environments. Pyrethroids have been found in sediment samples across wide areas of California, in both agricultural and urban watersheds, and have often been linked to toxicity observed in sediment toxicity tests. Pyrethroids are also under suspicion as a factor involved in the “pelagic organism decline”, or “POD”, which refers to the sharply reduced abundance of several important fish species in the Estuary in the past few years. Fortunately, pyrethroids are not persistent, so if their use is curtailed they would quickly cease to be a threat to Bay water quality. Whether such a reduction will occur, however, is unclear.

Sediment toxicity in the Bay is a problem that has persisted since the RMP began performing

sediment toxicity tests in 1993. In every year since 1993, 26% or more of sediment samples have been determined to be toxic to one or more test species. The toxicity tests indicate that pollutant concentrations in Bay sediments are high enough to affect the abundance of aquatic invertebrates. With plans for implementation of sediment quality objectives for the Bay in the next few years, these observations will begin to drive regulatory decisions. The pollutants causing this persistent toxicity have not yet been identified, and until they are, this problem is likely to persist into the future.

Organisms in the Bay are simultaneously exposed to a complex mixture of hundreds of chemicals. However, due to the difficulty of evaluating multiple chemicals at once, the vast majority of studies of pollutant effects on aquatic life have examined one chemical at a time. In spite of the lack of information on this topic, there is concern that pollutant mixtures could be combining to impair the health and reproduction of Bay wildlife. Pollutant mixtures could be affecting the early life stages of fish that are in decline, such as Delta smelt or striped bass. Mixtures could also be responsible for the Bay's persistent sediment toxicity, as well as impacts on Bay species from invertebrates on up to harbor seals and other species, including humans, at the top of the food web. However, there are many unknowns on this subject, including whether mixtures are having impacts on human and wildlife health, and, if they are, the sources of the key chemicals, spatial patterns and long-term trends, whether the problem is likely to persist into the future, and how to best address the problem.

A Short Answer

The Bay contains a complex soup of pollutants that vary in the severity and types of risks they pose, and in their sources, spatial distributions, and trends over time. Enforcement of the Clean Water Act and other environmental laws over the past 35 years has resulted in tremendous improvements in overall Bay water quality, solving serious problems related to organic waste, nutrients, and silver contamination.

Several significant water quality threats still remain, however, including mercury, PCBs, dioxins, and exotic species. The forecast for PCBs and dioxins is for slow progress toward recovery over the next 20 years, with concentrations likely to remain above risk thresholds. The outlook for mercury is unclear, and depends on whether effective management actions can be identified and implemented. For exotic species, the rate of introductions could be reduced significantly through management actions.

The future looks brighter for other pollutants (selenium, PAHs and legacy pesticides) whose concentrations do not exceed risk thresholds by much or at all, or it is not entirely clear if they pose significant risks in the Bay at present concentrations. Concentrations of selenium and PAHs could fall below risk thresholds in 20 years depending on management of sources. For legacy pesticides, concentrations should fall below risk thresholds in 20 years through natural breakdown, with lingering concerns only for effects in combination with other pollutants. For nickel and copper, concentrations are below thresholds and management plans are in place to make sure they stay there.

Concern for another group of pollutants is growing, due to either increasing rates of input into

the Bay or advances in scientific understanding of the magnitude of specific water quality threats. For PBDEs and pyrethroids the 20-year outlook is currently unclear, and will depend heavily upon management decisions. Concentrations of both of these pollutants would be expected to drop rapidly in response to reduced inputs to the Bay. If use of these chemicals is curtailed, the RMP should be looking ahead to evaluate the risks associated with the next generation of popular flame-retardants and insecticides, which hopefully will be less of a threat to Bay water quality. The outlook for sediment toxicity will be unclear until the causes of this toxicity can be identified. Too many unknowns surround the issue of risks due to pollutant mixtures to characterize current status, much less the status in 20 years.

Continued monitoring and advances in scientific understanding will be essential in refining the forecasts for the Bay's assortment of pollutants of concern, and in tracking the response of the ecosystem to management actions taken to continue the general trend toward improvement of Bay water quality that has occurred over the past several decades.

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