Watershed Management of Mercury

in the

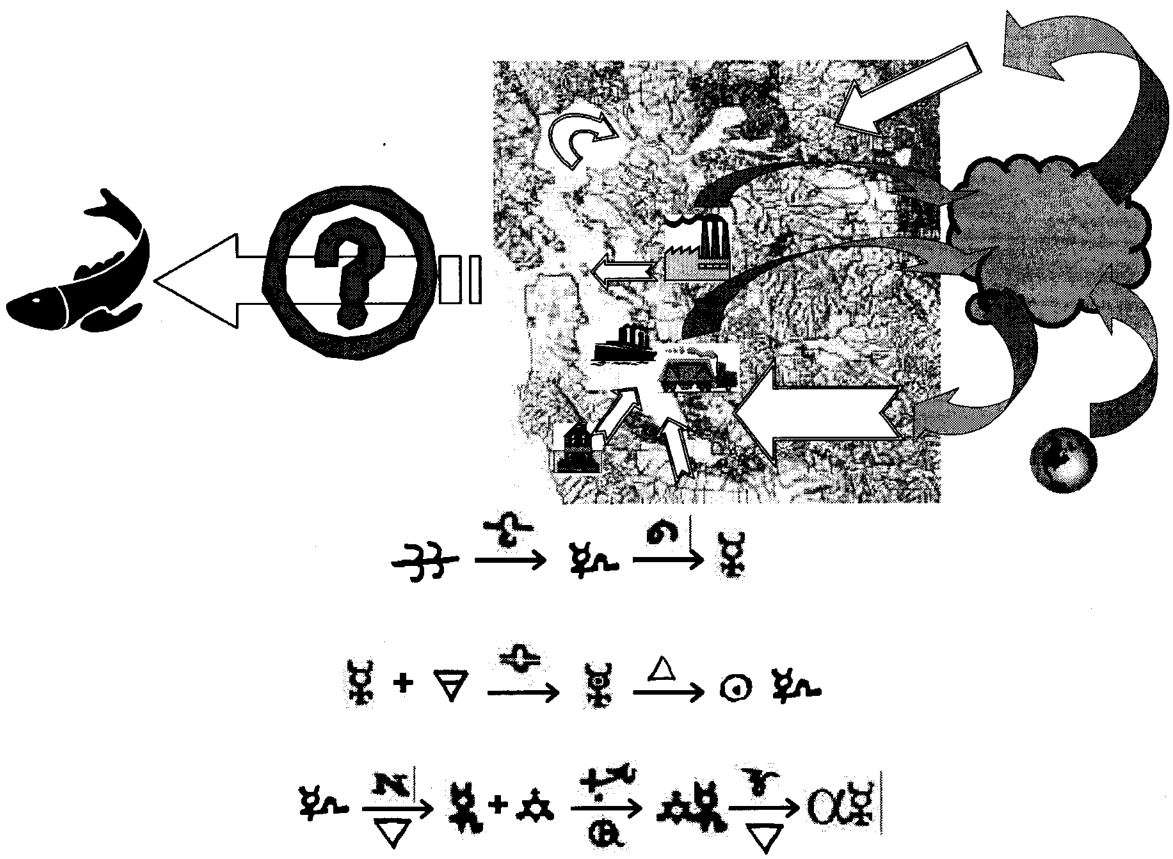
San Francisco Bay Estuary:

Total Maximum Daily Load

Report to U.S. EPA

California Regional Water Quality Control Board
San Francisco Bay Region

June 30, 2000



Acknowledgements, Authorship, and Dedications

This report is a synthesis of science, policy, values, and ideas brought forward by a diverse group of stakeholders. Literally hundreds of participants have engaged staff of the California Regional Water Quality Control Board on the subject of mercury in the environment; their interest and participation are greatly appreciated. Many individuals have directly contributed time, thought, and energy into this report and the deliberations leading to it, and should be recognized explicitly. Their names appear on the following two pages.

"Let every man make known what kind of government would command his respect, and that will be one step toward obtaining it."
Henry Thoreau, *Civil Disobedience*

"And now, let the wild rumpus start!"
Maurice Sendak, *Where the Wild Things Are*

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Cover design by Khalil Abu-Saba. The upper section depicts the numerous pathways conveying mercury into the aquatic ecosystem of the San Francisco Bay estuary, and the uncertainty about how mercury from each pathway is bioaccumulated. The lower section depicts the biogeochemical cycle of mercury, in seventeenth century alchemical symbols, from cinnabar, to quicksilver used in gold amalgamation, to inorganic mercury, to methylmercury in fish.

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Definition of Acronyms and Abbreviations

ATSDR	Agency for Toxic Substance Disease Registry
BAF	Bioaccumulation Factor
BADA	Bay Area Dischargers Association
BASMAA	Bay Area Stormwater Management Agencies Association
COMM	Ocean, Commercial, and Sport Fishing Beneficial Use
CTR	California Toxics Rule
CWA	Clean Water Act
CVRWQCB	California Regional Water Quality Control Board, Central Valley Region
ESA	Endangered Species Act
F_{63}	Percent fine grain material less than 63 μm, expressed as a fraction
FDA	Food and Drug Administration
FWS	Fish and Wildlife Service
GLWQI	Great Lakes Water Quality Initiative
$[Hg]_{norm}$	Mercury concentration normalized to percent fines (<63 μm)
$[Hg]_{sed}$	Mercury concentration of in sediment
$[Hg]_{ss}$	Mercury concentration of suspended sediments
$[Hg]_{tot}$	Mercury concentration of total recoverable in water
$[MeHg]_{fish}$	Methylmercury concentration in fish tissue
$[MeHg]_{water}$	Methylmercury concentration in water
MRC	Mercury Report to Congress
NAS	National Academy of Science
NPDES	National Pollutant Discharge Elimination System
OEHHA	Office of Environmental Health Hazard Assessment
RARE	Preservation of Rare and Endangered Species Beneficial Use
RMP	San Francisco Estuary Regional Monitoring Program for Trace Substances
SFBRWQCB	California Regional Water Quality Control Board, San Francisco Bay Region
SFEI	San Francisco Estuary Institute
SRWP	Sacramento River Watershed Program
TMDL	Total Maximum Daily Load
WILD	Wildlife Habitat Beneficial Use
WSPA	Western States Petroleum Association
WQO	Water Quality Objective

Executive Summary

Background & Problem Definition

The San Francisco Bay Regional Water Quality Control Board has listed all segments of San Francisco Bay as impaired due to mercury pollution. This listing is based on exceedance of the Basin Plan numeric objective for mercury in water (0.025 μg/L), and because of the potential for mercury to bioaccumulate in fish. Analysis of fish caught in San Francisco Bay shows that some species (e.g., leopard sharks) exceed the FDA limit for mercury in fish (1 μg/g). Individual striped bass approach this limit. Other fish caught in the bay (e.g., halibut, shiner surf perch, white croaker, sturgeon, jacksmelt) have median concentrations ranging from 0.09 – 0.27 μg/g. Although many species are below the FDA action level, the finding of impairment is substantiated by recent measurements of dissolved methylmercury at levels that may indicate unacceptable health risk to humans and aquatic birds. Furthermore, the FDA action level is not the final word on acceptable mercury levels in fish. The National Academy of Sciences has convened a panel of experts that is expected to deliver a report in July 2000 on human health risks due to dietary mercury exposure. The conclusions of that scientific review will have important implications for our finding of impairment and subsequent regulatory actions.

Because mercury is a potent neurotoxin that affects developing fetuses and young children, the Regional Board has made removing impairment due to mercury a high priority. Despite substantial (>90%) reductions in mercury loads from wastewater sources over the past thirty years, mercury concentrations in Bay sediments do not appear to have improved. Sediments act as the repository for mercury in the Bay. Elevated mercury concentrations in sediments are the reason that the water quality objective is exceeded. Sediments are still contaminated despite stringent controls on point sources because there are ongoing loads from other watershed sources, namely inoperative coast range mercury mines.

When standards are not attained despite control of wastewater point sources, the Clean Water Act requires that a total maximum daily load (TMDL) be developed. A TMDL expresses the maximum amount of a pollutant that a waterbody can receive and still attain standards within a reasonable amount of time. That load is then allocated to all sources in the watershed, point and nonpoint, which must implement control measures as needed to reduce loads to the levels allocated.

Regulations and guidance provides for establishing a phased TMDL when additional information needs to be gathered. In this report, we propose a phased TMDL that regulates to meet a sediment target in the first phase, and more sophisticated targets in the second phase that are indicators of bioaccumulation in aquatic food chains.

Numeric Targets

A TMDL is based on numeric targets that equate to attainment of standards. Control measures are directed at meeting numeric targets. For this TMDL report, we have derived two numeric targets directly from our Basin Plan narrative objective for bioaccumulation:

> Many pollutants can accumulate on particles, in sediment, or bioaccumulate in fish and other aquatic organisms. Controllable water quality factors shall not cause a detrimental increase in concentrations of toxic substances found in bottom sediments or aquatic life. Effects on aquatic organisms, wildlife, and human health will be considered.

The first numeric target is directed at mercury accumulation in bottom sediments. The second numeric target is directed at mercury accumulation in aquatic life.

Figure 1 helps understand how "accumulation in sediments" can be quantified. Mercury concentrations in sediments tend to increase with the percentage of fine (silt –clay) particles present. The heavy, black line in Figure 1 is consistent with the mercury – percent fine relationship observed in Sediments from the Sacramento River, which supplies >80% of the total sediment load to San Francisco Bay. Significant deviations from this line indicate mercury sources to the Bay.

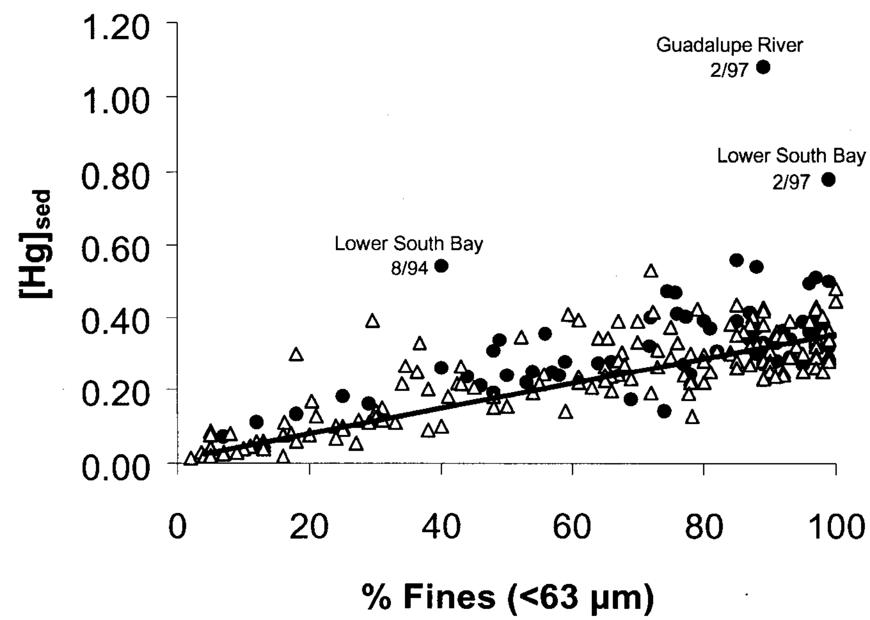

Figure 1: Mercury concentrations (µg/g) in San Francisco Bay sediments vs. percent fines (<63 µm). Graph of 225 data points from the RMP, 1993-1997 [1]. Open triangles depict northern reach sediments, closed circles depict South Bay sediments. The heavy black line shows the best fit linear regression on the lower 75'th percentile of the data.

Conceptually, the sediment target is represented by the heavy black line in Figure 1. Mathematically, the sediment target is expressed as the concentration of mercury in sediments divided by the percentage of fine material (<63 μm) present:

$$[Hg]_{norm} = [Hg]_{sed} / (F_{63})$$

Where:

$[Hg]_{norm}$	= Sediment concentration normalized to percent fines (μg/g)
$[Hg]_{sed}$	= Bulk sediment concentration (μg/g)
F_{63}	= Percent fines (<63 μm), expressed as a fraction ($0 \leq F_{63} \leq 1$)

This target is the median value for $[Hg]_{norm}$ in sediments coming from the Sacramento River, 0.40 μg/g. We propose to establish load and wasteload allocations based on attainment of this target in the first phase of the TMDL.

The second numeric target, directed at mercury accumulation in aquatic organisms, is dissolved methylmercury in water. Dissolved methylmercury in water is magnified ten million fold in fish through a process known as bioaccumulation. Therefore, a concentration of 0.1 ng/L methymercury in water can lead to a mercury level of 1 μg/g in fish. We have proposed a conservatively low target of 0.05 ng/L for methylmerury in water to provide a margin of safety and account for wildlife protection concerns. This target should maintain mercury levels in fish at or below 0.5 μg/g, or one-half of the FDA action level.

Overall, most of the Bay is below the target for methylmercury. Preliminary results show that the median dissolved methylmercury concentration for the entire bay is 0.02 – 0.03 ng/L. However, we need more information from the margins of the estuary, where methylmercury production rates are likely higher than in the open water. The highest methylmercury concentration in water observed anywhere in the estuary thus far is in Guadalupe Slough, in Lower South Bay. Thus, although we are proposing to use the methylmercury target in the second phase, it is still a useful indicator to verify that control measures directed at attaining the sediment target also address mercury accumulation in aquatic ecosystems.

Source Assessment

The largest mercury loadings to the estuary come from the sediments transported by the Sacramento River (Figure 2). This represents a combination of weathering of parent rock in the Central Valley Watershed, atmospheric deposition of mercury, and inputs of polluted sediments from inoperative Coast Range mercury mines and Sierra foothills gold mines. Of these three processes, only the inputs from mining legacy sources are considered to be readily controllable on a watershed scale.

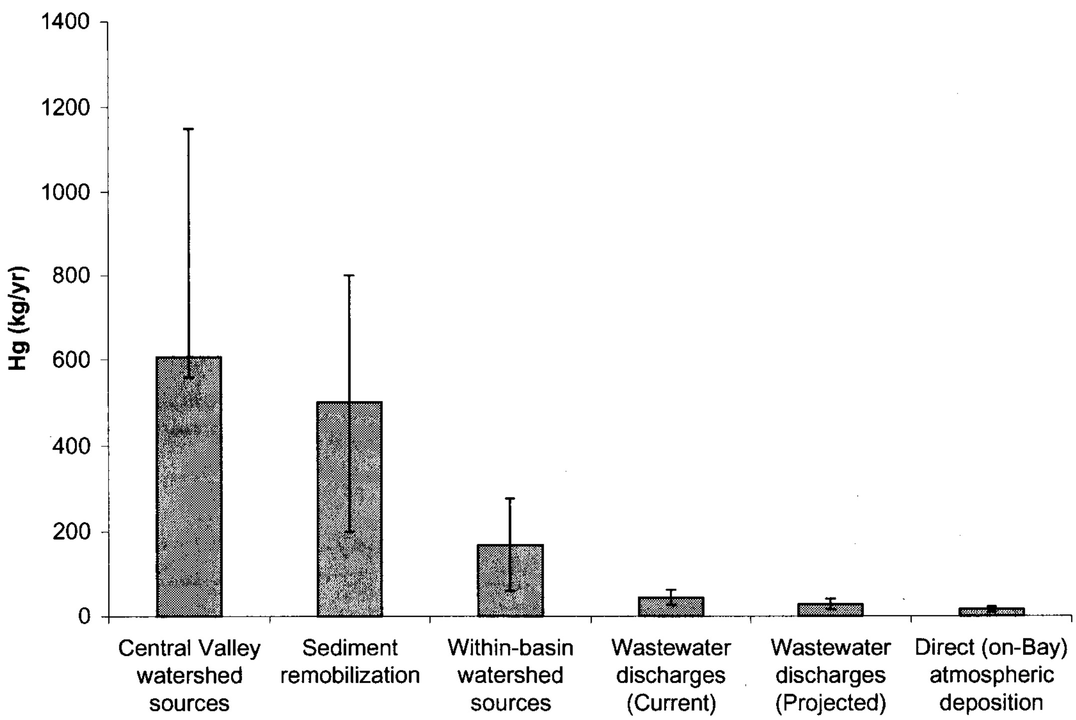

Figure 2: Summary of annual mercury loads to all of San Francisco Bay. Current wastewater loads reflect our best current estimates. Projected wastewater loads reflect estimates based n preliminary results of low-level wastewater analyses implemented in January, 2000.

Remobilization of historically polluted sediments may be another substantial source of mercury, although there is considerable uncertainty as to the size of the load. During and after the hydraulic mining era of the late 1800's, over a billion cubic yards of mercury-laden sediment was deposited in San Pablo Bay. Today, portions of that material are being exposed by erosion. This is essentially a background process; there is little that can be feasibly done to reverse ongoing loads from exposure of historic pollution in bedded sediments.

Watershed sources within our basin probably represent the largest controllable mercury source. As with the Sacramento River, watershed loads of mercury are derived from erosion of the parent rock, atmospheric deposition, and inputs of polluted sediments from inoperative coast-range mercury mines. The latter is a dominant process in the Guadalupe River watershed, and directly contributes to detrimental increases in mercury concentrations in sediments of Lower South Bay (Figure 1). The source of this is the New Almaden mining district, which was at one time the largest producer of mercury in North America. The waste rock from ore processing was dumped in creek beds throughout the upper Guadalupe watershed. Now those creeks are downcutting through the waste material, transporting highly polluted sediments into the lower watershed, and from there into Lower South Bay. Transport of polluted sediments from the Guadalupe River watershed brings approximately 50 kg mercury per year into Lower South Bay.

Mercury loadings from other watersheds within the San Francisco Bay region are not as well characterized as the Guadalupe River. We have estimates of sediment production for each watershed, and can use those to estimate mercury loadings. Watershed loads vary with annual rainfall. Overall, watershed processes throughout the Bay Area amount to 32-155 kg during dry years, 58-278 kg during normal years, and 90-463 kg during wet years. These estimate of watershed loads include both urban runoff and runoff from non-urbanized areas.

Quantifying the effect of air sources on mercury loadings to the aquatic ecosystem is extremely complex. We estimate that approximately 370 kg of mercury are released into the atmosphere each year in our region, but it is unknown how much of that enters the aquatic ecosystem. The Regional Monitoring Program has begun a pilot study of mercury deposition rates. Based on deposition rates from other urbanized areas, we estimate that direct deposition onto the Bay waters amounts to 3-35 kg per year. Of this, 0.5-7 kg per year comes from the global background deposition rate of mercury, and the remainder from regional sources. Atmospheric deposition can also contribute to watershed loading rates. In urbanized areas, we estimate that up to 25% of watershed loads could be derived from atmospheric deposition.

Of all known sources, wastewater dischargers have attained the most substantial mercury reductions over the past three decades, by investing over two billion dollars in construction of wastewater treatment systems. Today, wastewater dischargers release between 25 and 62 kg of mercury per year into the entire Bay. We have recently required better mercury measurements from all wastewater dischargers, and expect this estimate to be refined to 20-45 kg per year as new data are produced.

Linkage Analysis

The linkage analysis defines the connection between numeric targets and identified sources. The linkage is defined as the cause and effect relationship between the selected indicators, the associated numeric targets, and the identified sources. It provides the basis for estimating total assimilative capacity and any needed control measures.

In the first phase of the TMDL, we propose load and wasteload allocations based on attaining the sediment target. The sediment target identifies ongoing sources that cause or contribute to violation of our Basin Plan narrative objective for bioaccumulation. The dissolved methylmercury target links sources to accumulation in aquatic organisms.

Load and Wasteload Allocations

We have divided the Bay into segments. For the Lower South Bay segment, we require a load reduction of 45 kg per year from the Guadalupe River watershed, based on attainment of the sediment target.

To get some sense of the scope of this reduction, consider that most of the mercury load from the Guadalupe River is in the form of sediments with mercury concentrations around 1 μg/g (parts per million). So one kilogram of mercury is equivalent to one million kilograms of sediment. A large truck, such as the kind servicing a quarry, holds about a million kilograms of sediment. To meet the load allocation for the Guadalupe River watershed, every year enough sediment to fill 45 large trucks has to be intercepted and removed. If hot-spots are found that have an average of 10 μg/g mercury, then the load allocation could be met by removing 4-5 large trucks per year. These numbers give some practical meaning to the load allocation proposed for the Guadalupe River watershed.

All watershed sources, both urban and non-urban runoff, must meet the mercury sediment target (0.40 μg/g, normalized to percent fines). In watersheds where the target is exceeded, we propose to conduct source investigations and issue waste discharge requirements to control sources as needed. Urban runoff programs are responsible for ensuring that their stormwater conveyances also comply with the sediment target.

The numerical wasteload allocation, in kg per year, for an urban runoff programs depends on the sediment load conveyed. That load, in turn, varies with annual rainfall. To derive a rigorous numeric wasteload allocation for a particular urban runoff point of discharge, we would need information on the sediment load from that point. In the absence of such information, we simply hold urban runoff programs responsible for ensuring that the sediment target is attained in the receiving waters impacted by their conveyances.

In other words, we assign a load allocation to each of the watershed catchements in the Bay Area based on estimated sediment production. The load from each of those catchements is the sum of both urban runoff wasteloads and background watershed loads. In the first phase of the TMDL, we propose to hold urban runoff programs responsible for attaining the load allocation for all watershed catchements in their jurisdiction. If an urban runoff management agency wishes to develop a separate wasteload allocation for their urban stormwater conveyances, they must provide reasonable estimates of the sediment load from those conveyances, and assess compliance with the sediment mercury target.

The watershed reductions proposed for the first phase address the largest ongoing sources of mercury. There is also good evidence from other regions of the country that atmospheric deposition of mercury can contribute to elevated mercury levels in fish. In 1999, we began assessing atmospheric deposition rates through the Regional Monitoring Program. Although the data from that study are not yet available, and we need a better linkage between deposition rates in the watershed and bioaccumulation, the scientific evidence available shows that reduction of air sources is warranted.

We estimate that approximately 370 kg of mercury per year is released into the atmosphere in the Bay Area. In the first phase of the TMDL, we will assign a load allocation to atmospheric emissions that requires a reduction by 19% of total current releases. That amounts to a reduction of 70 kg per year, if our current estimates are correct. This is a feasible reduction, in that most of it could be realized by controlling emissions from fluorescent light breakage alone.

Concurrent with load reductions from air sources, we will continue to investigate deposition rates and conveyances to the aquatic ecosystem. In the first phase of the TMDL, we will seek to better quantify the linkages between airborne emissions, airborne deposition, and production of methylmercury. Urban runoff programs are the regulated entities most likely affected by atmospheric deposition of mercury. We are therefore asking urban runoff programs to help negotiate reduction of atmospheric emissions of mercury in a voluntary, cooperative approach during the first phase of the TMDL. In the second phase, if clear linkages have been established between atmospheric deposition and mercury loads in urban runoff, and no progress has been made towards reduction of atmospheric emissions, more prescriptive measures may be required.

The sum of wasteload allocations for wastewater should be less than 50 kg in the entire San Francisco Bay watershed. The limit of 50 kg for all wastewater sources is based on the sediment target and the narrative objective for bioaccumulation. Limiting wastewater discharges to 50 kg baywide ensures that, at most, wastewater sources contribute 0.01 μg/g to the baywide average mercury concentration in sediments (0.30 μg/g). This limit will be allocated to individual sources according to the vulnerability of the receiving waters. Shallow water outfalls discharge into areas more prone to mercury methylation, and therefore should get proportionally lower wasteload allocations than deep water discharges.

The proposed wasteload allocations should not cause undue economic impacts, because they are attainable through current technology without undue restrictions on growth. Any treatment plant in the Bay Area should be able to attain an annual average mercury concentration of 0.025 μg/L. Furthermore, plants with shallow water outfalls should be able to attain an annual average concentration of 0.015 μg/L. In Lower South Bay, wastewater treatment plants have shown that they can meet an annual average concentration of 0.007 μg/L. We have allocated loads using these performance goals and double current flow rates. The sum of these mass limits for all municipal and industrial dischargers is less than 50 kg. This approach limits total the mass of mercury released from wastewater discharge to levels very close to current performance, while allowing reasonable room for growth and placing the burden of increased treatment on facilities with the poorest performance. We will continue to investigate possible linkages between wastewater inputs and methylmercury production. As we refine the methylmercury target and gain a better understanding of methylmercury distributions in the estuary, it may be necessary to impose more stringent mass limits on individual wastewater dischargers. The scope of proposed actions is summarized in Figure 3.

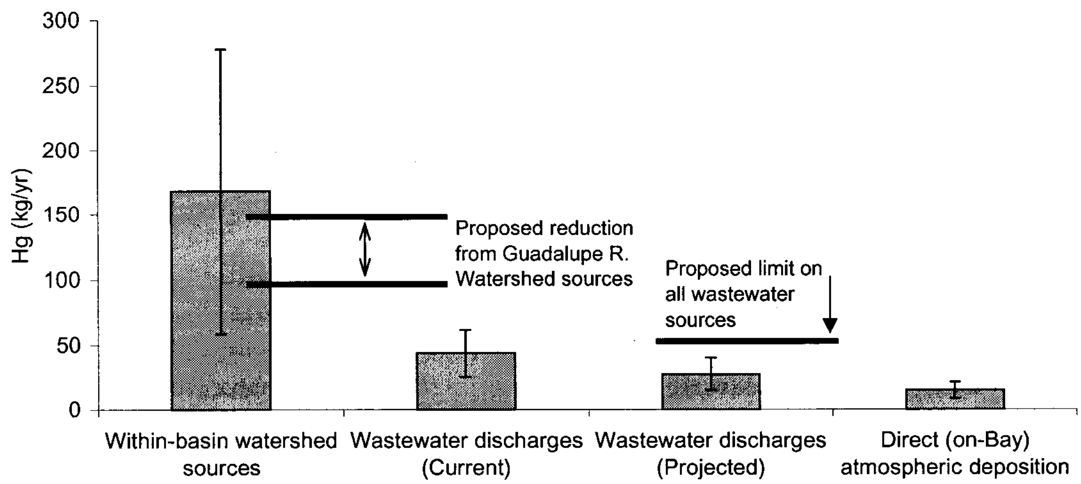

Figure 3: Summary of controllable sources within the San Francisco Bay watershed and effect of proposed load and wasteload allocations.

Other Regulatory Considerations

Wetland creation and management is one of the most important issues that needs to be addressed using the more sophisticated targets proposed for phase two. Methylmercury production is enhanced in wetlands because of increased microbial activity. Essentially all wetlands surrounding the Bay are managed wetlands. There may be significant reductions possible in the overall production of methylmercury within the Bay margins that can be realized by manipulating physical factors such as degree of inundation, salinity, vegetation, and source sediment. When we do anything related to wetlands construction, restoration, mitigation, or management, we want to make sure that the net contribution of methylmercury to the ecosystem is reduced.

Although reducing methylmercury production is a sound goal for removing mercury impairment, we simply do not have the science at present to guide basin-scale policy decisions related to mercury methylation in wetlands. We need to know more about current methylmercury concentrations and production rates in wetlands and tidal mudflats. We need to be able to quantify the susceptibility of mercury in sediments to methylation (its *bioavailability*), to guide our choices in the use or disposal of dredged material. We need to relate wetland design and management practices to methylmercury production rates. This is all science information that will be developed during the first phase of the TMDL, for incorporation in the second phase as policy adopted through public process.

Knowing the bioavailability of mercury in sources is also essential to coordinating the San Francisco Bay mercury TMDL with the Sacramento River watershed mercury TMDL. The Central Valley Region has numerous coast-range mercury mines and mercury hot spots associated with former gold mines in the Sierra foothills, where mercury was used to extract gold from placer deposits. Because the degradation rate of methylmercury is typically short compared to the residence time of water in the Bay, in-Bay production of methylmercury is likely much more important than direct export of methylmercury from the Central Valley into San Francisco Bay. The Central Valley Regional Board has undertaken a three year study, in collaboration with CalFED, to assess the bioavailability of mercury in its sources. We will use their findings to review our TMDL and set load allocations for the Sacramento River watershed in the second phase, in coordination with the Central Valley Regional Water Quality Control Board.

The second phase of the TMDL will establish additional targets. The science supporting the FDA action level of 1 μg/g mercury in fish is currently under national review. When that review is complete, and we have gathered more information on fish consumption in the Bay Area, we can establish a fish tissue target specific to San Francisco Bay. We also need to develop a bioconcentration factor for methylmercury which is specific to our own estuary, so that the methylmercury target can be revised to reflect the updated fish tissue target. In phase two we will also establish an avian egg target, to protect the most sensitive life stage of wildlife inhabiting the Bay. After establishing fish tissue and avian egg targets, and revising the methylmercury target as appropriate, we will review the TMDL.

In summary, this report presents a two-phased watershed management strategy for mercury in San Francisco Bay, within the framework of the Clean Water Act requirement for establishing a TMDL in impaired waterbodies. The first phase uses data from the Regional Monitoring Program to establish a target for mercury in sediments. The sediment target directs control measures at the most flagrant cause of impairment: coast range mercury mines in our own watershed. At the same time, we have established a preliminary target for methylmercury to protect people and wildlife, and are developing information to help establish a TMDL based on methylmercury production in the second phase.

To bring this report before the Board for adoption as a Basin Plan amendment, we need an implementation plan. Outstanding issues that need to be resolved for that implementation plan include securing commitments from the entire regulated community to participate in TMDL implementation, assignment of accountability for attaining the watershed load allocations, and regulation of cross-media air sources. We intend to work with our existing stakeholder forum, the Mercury Council, to resolve these and other outstanding issues. The final TMDL needs scientific peer review and an analysis of economic impacts for adoption as a Basin Plan amendment. We also invite stakeholders and interested parties to provide comments on the technical and policy aspects of this watershed plan.

In the interim, the Regional Board has regulatory authority under the existing Basin Plan and current State regulations to address the most urgent priorities for control of mercury from watershed sources. Section 13267 of the California Water Code allows the Regional Board to administratively request monitoring information. Waste Discharge Requirements and Cleanup and Abatement Orders are also important regulatory tools that can be used when we have clear linkages to impairment of beneficial uses. The Regional Board will also place heightened attention to methymercury in the conduct of site investigations and remediations within the watershed. The science presented in this report shows that we have enough knowledge about mercury in our watershed to act immediately and sensibly on the largest sources of impairment, while concurrently planning a course of action that addresses more subtle impacts.

Key Points in the Executive Summary

- San Francisco Bay is listed as impaired due to mercury pollution.
- The finding of impairment is based on exceedance of the Basin Plan water quality objective, and mercury levels in fish.
- A TMDL is required by the Clean Water Act to control all sources within the watershed.
- This is a phased TMDL approach.
- The first phase is directed at a target for mercury concentrations in sediments.
- The first phase also establishes a target for methylmercury in water, to protect people and wildlife.
- Both targets identify the Guadalupe River watershed as an ongoing source contributing to impairment of beneficial uses.
- The first phase proposes strict load allocations for the Guadalupe River watershed, reductions of atmospheric emissions by 70 kg, and mass limits for wastewater dischargers based on minimizing accumulation in sediments and protection of shallow receiving waters.
- The second phase will use more sophisticated targets to address wetland management and inputs from the Sacramento River watershed.
- There are outstanding issues that need to be resolved before bringing this before the Regional Board for adoption.
- In the interim, the Regional Board has regulatory authority to require source investigations and control inputs that clearly contribute to degradation of the Bay.

1. Background

1.1 Description of the TMDL process

The San Francisco Bay estuary is a valuable natural resource in the State of California. Water quality standards are set and enforced by the State of California to protect the designated uses of its water bodies. When states and local communities identify problems in meeting water quality standards, a Total Maximum Daily Load (TMDL) can be a part of a plan to fix the water quality problems. The purpose of this TMDL is to identify the mercury control measures and additional information needed to meet water quality standards set for San Francisco Bay and to guide the implementation of control measures and monitoring programs.

Section 303(d) of the of the Clean Water Act (CWA) requires states to identify waters where the effluent limitations required under the National Pollutant Discharge Elimination System (NPDES) or any other enforceable limits have been implemented and adopted water quality standards are still not attained. Lists of prioritized impaired water bodies are known as the "303(d)" lists and must be submitted to the United States Environmental Protection Agency (U.S. EPA) every two years.

A TMDL represents the total loading rate of a pollutant that can be discharged to a waterbody and still meet the applicable water quality standards. The TMDL can be expressed as the total mass or quantity of a pollutant that can enter the water body within a unit of time. In most cases, the TMDL determines the allowable loading capacity for a constituent and divides it among the various contributors in the watershed as wasteload (for point source discharge) and load (for nonpoint source) allocations. The TMDL also accounts for natural background sources and provides a margin of safety.

For some nonpoint sources it might not be feasible or useful to derive an allocation in mass per time units. In such cases, a percent reduction in pollutant discharge may be proposed, recognizing that the reduction is in comparison to a specific baseline estimated loading level. The resultant loading level must, when summed with other allocations, be less than or equal to the TMDL itself.

U.S. EPA has described a phased approach to TMDL development for situations where data and information needed to determine the TMDL and associated allocations are limited. The phased approach is essential to developing a TMDL for mercury in San Francisco Bay. There is significant uncertainty associated with risk assessment, estimates of assimilative capacity and several loading sources. Nonetheless, the Source Assessment (Section 4) clearly identifies substantial ongoing sources, and the Linkage Analysis (Section 5) demonstrates the importance of controlling these ongoing sources. In accordance with U.S. EPA guidance, this phased TMDL contains a monitoring and review plan and demonstrates the practicability of the proposed nonpoint source allocations.

TMDLS must include specific information to be approved by the U.S. EPA. This information can be summarized by the following seven elements:

1. **Plan to meet State Water Quality Standards**: The TMDL includes a study and a plan for the specific waters and pollutants that must be addressed to ensure that applicable water quality standards are attained.

2. **Describe quantified water quality goals, targets, or endpoints**: The TMDL must establish numeric endpoints for the water quality standards, including beneficial uses to be protected, as a result of implementing the TMDL. This often requires an interpretation that clearly describes the linkage(s) between factors impacting water quality standards.

3. **Analyze/account for all sources of pollutants**: All significant pollutant sources are described, including the magnitude and location of sources.

4. **Identify pollution reduction goals**: the TMDL plan includes pollutant reduction targets for all point and nonpoint sources of pollution. TMDLs, load allocations, and wasteload allocations indicate maximum allowed loads. Percentage reductions can also be provided, and allocations should be compared with current loads to show level of reduction needed.

5. **Describe the linkage between water quality endpoints and pollutants of concern**: The TMDL must explain the relationship between the numeric targets and the pollutants of concern. That is, will the recommended pollutant load allocations lead to attainment of the target?

6. **Develop margin of safety that considers uncertainties, seasonal variations, and critical conditions**: The TMDL must describe any uncertainties regarding the ability of the plan to meet water quality standards. The plan must consider these issues in its recommended pollution reduction goals.

7. **Include an appropriate level of public involvement in the TMDL process**: This is usually achieved by publishing public notice of the TMDL, circulating the TMDL for public comment, and holding public meetings in local communities.

Section 1.1 Key Points:

- A TMDL is a plan to meet water quality standards.
- A TMDL is required when effluent limits alone do not fix water quality problems.
- A description of the maximum pollutant load a waterbody can handle is fundamental to TMDL development.
- The U.S. EPA allows development of a phased TMDL when more information is needed.
- The U.S. EPA has specific guidance for what has to be in a TMDL.

1.2 Regulatory Context

In the San Francisco Bay estuary, the Clean Water Act is administered by the California Regional Water Quality Control Board, San Francisco Bay Region (the Regional Board) under its Federally designated authority. This Regional Board is one of nine other regional boards in California, each generally separated by hydrogeological boundaries. The State Water Resources Control Board (State Board) establishes statewide policies and serves as the review and appeal body for the decisions of the regional boards. The State Board is made up of five members appointed by the governor.

The Regional Board consists of nine governor-appointed members who serve four year terms. Science information is gathered and policy is developed for the Regional Board by its civil service employees (staff), currently numbering approximately 100 in the San Francisco Bay Region. The Regional Board has adopted a Water Quality Control Plan (Basin Plan) that specifies water quality standards for the San Francisco Bay basin, and implementation measures to enforce those standards.

Some measures that go beyond the scope of the current Basin Plan must first be adopted by the Regional Board in a Basin Plan amendment process before they are implemented. Such measures include the TMDL that is the subject of this report. The process involves presenting proposed Basin Plan amendments to the Regional Board in a publicly noticed hearing. The Regional Board receives public comments, and at least sixty days later, staff present responses to comments and relevant revisions to the proposed amendment. The Regional Board then votes on adoption, and if the amendment is adopted, it is sent to the State Board for approval. If the State Board approves the amendment, it is sent to the Office of Administrative Law (OAL) to determine whether the amendment is consistent with the California Adminstrative Procedures Act (APA). State TMDL adoption is complete after OAL approval and State transmittal of the TMDL to the U.S. EPA for approval.

The entire Basin Plan amendment process can take one to three years to proceed through all steps. The U.S. EPA has authority to promulgate its own regulatory actions if they believe that the State process is not meeting the requirements of the Clean Water Act in a reasonable amount of time. The U.S. EPA has already taken such measures in California, the most notable being setting numeric criteria for water quality in the California Toxics Rule. The U.S. EPA has also indicated that it may establish the TMDL if necessary.

TMDL development should include consultation with federal and state wildlife agencies. The United States Fish and Wildlife Service (U.S. FWS) may issue a jeopardy opinion on any federal action that puts threatened or endangered species in jeopardy. U.S. EPA's obligation to the Endangered Species Act is currently under discussion, so the implications of a jeopardy opinion are not clear at the present. Nonetheless, this TMDL report has been developed in close collaboration with U.S. FWS staff, who have directly contributed data for the problem statement and are working with Regional Board staff to develop numeric targets protective of endangered wildlife.

A draft report defining the mercury problem and a proposed San Francisco Bay strategy was circulated for public comment in June of 1998 [2]. The report was formally presented before the Regional Board in December, 1998. In early 1999, a stakeholder forum (the Mercury Council) was formed to discuss and revise the proposed strategy. After several meetings of the Mercury Council and its work groups, the Regional Board was updated on the deliberation of the Mercury Council in October, 1999, and again in March 2000. Throughout these proceedings, two clearly identified goals have been articulated before the Regional Board:

1) Reduce loadings so that input rates are less than removal rates
2) Focus control measures on processes that bioconcentrate mercury

This TMDL report addresses those goals by incorporating stakeholder recommendations with the best available science to derive early source reduction actions and long term monitoring strategies to close information gaps. The science influencing this report includes over a hundred peer-reviewed publications and ten years worth of data from the San Francisco Bay Regional Monitoring Program for Trace Substances (RMP). The RMP is a program ordered by the Regional Board, funded by the regulated entities in the region, and administered by the San Francisco Estuary Institute (SFEI) on a budget that is currently $2.6 million a year. The RMP has made over twenty thousand environmental quality measurements[1], including dissolved and total mercury in water, mercury in sediments, mercury in fish and shellfish, and recently, methylmercury in sediments and water. This information is fundamental to defining the mercury problem in San Francisco Bay.

In 1998, the State Board committed to delivering two "TMDL reports" per year from each region as a condition of TMDL grant funding. This report fulfills one of the two deliverables due from the San Francisco Bay Region in April, 2000. A "TMDL report" contains all of the elements of a TMDL except an implementation plan. Because of the possibility of federal promulgation, this report also includes specific recommendations for implementation.

Section 1.2 Key Points:

- Federal and State water quality law in the San Francisco Bay estuary is administered by the Regional Water Quality Control Board (Regional Board)
- The Regional Board defines water quality standards in its Basin Plan, and has authority to enforce those standards.
- Implementation items not currently within the scope of the Basin Plan will require Basin Plan amendments, which can take up to three years to fully adopt.
- A mercury watershed strategy was first presented to the Regional Board in a public hearing in 1998.
- In 1999 - 2000, a series of stakeholder meetings was convened by staff to help refine that strategy.
- This TMDL fulfills a deliverable obligation that the State Water Resources Control Board has made to the United States Environmental Protection Agency

1.3 Watershed Description

1.3.a Physical Description

The San Francisco Bay watershed[1] (Figure 4) consists of eighty separate drainage basins having a total area of 3,465 square miles (8.97 x 10^{9} m^2) (SFBRWQCB 1975). The surface area of San Francisco Bay system, including San Pablo and Suisun Bays, and mudflats, is 479 mi^2 (1.24 x 10^{9} m^2) (Conomos 1979). The average depth is 20 feet (6.1 m). The water volume of the Bay system at mean sea level is 235 billion cubic feet (6.66 x 10^{9} m^3). The tidal prism, or volume between mean higher-high water and mean lower-low water, is 24 percent of the volume of the Bay or 56 billion cubic feet (1.59 x 10^{9} m^3).

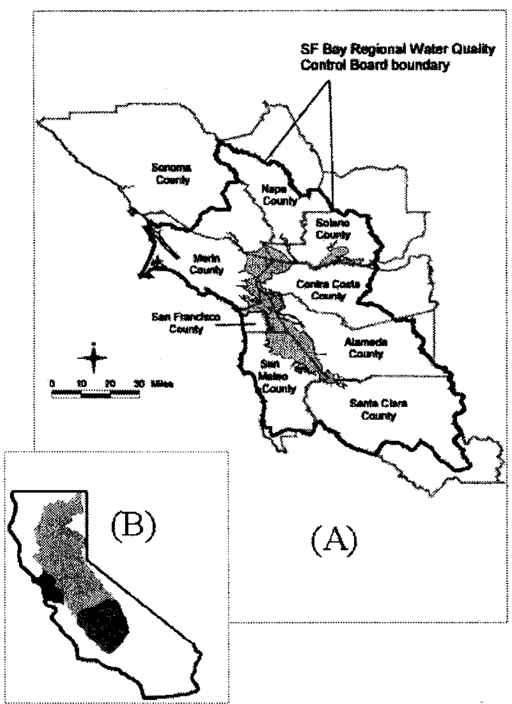

Figure 4: Location map for the San Francisco Bay Watershed, California. (A) Watershed boundaries and county lines. (B) Location of watershed within the State of California. Black area shows San Francisco Bay watershed (Region 2), gray areas show Central Valley watershed (Region 5) that drains into Region 2. The dark gray sub-watershed is an inland drainage that only flows into the San Francisco Bay during extremely wet years.

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[1] This is the watershed that is under the authority of this Board (the California Regional Water Quality Control Board, San Francisco Bay Region). In physical reality, the San Francisco Bay serves as the drainage outlet for waters of the three Central Valley basins. In total, this larger watershed encompasses 45,912 square miles (1.2 x 10^{11} square meters). The local San Francisco Bay watershed is politically separated from the Central Valley basins by a boundary located in the delta between Winter Island and Sherman Island, and between the cities of Pittsburg and Antioch. It is the smaller watershed west of this boundary that is the focus of this report.

1.3.b Tributaries

Rivers and streams in the basin contribute fresh water flows of 67 billion cubic feet per year (1.9 x 10^{9} m^3/yr) (Conomos 1979). The San Francisco Bay also serves as the primary outlet for the drainage from the Central Valley basins. It receives an average annual outflow of 670 billion cubic feet (19 x 10^{9} m^3/yr) of fresh water from the Central Valley. The outflow occurs during winter and spring with the highest flow generally between the months of January and April.

1.3.c Landscape/Geology

The topography of the watershed is dominated by the Coastal Ranges consisting of mountains and ridges that stretch generally north-south for 600 miles from Eureka to Santa Barbara. The Golden Gate provides the only break. North of Monterey and San Benito Counties, the Coastal Ranges split into two distinct ranges, the Diablo Range and the Santa Cruz Mountains. The latter, with elevations between 1,500 and 2,000 feet (460 to 610 m) are located west of the Santa Clara Valley and form the San Francisco Peninsula. North of this, the Bolinas Ridge and Mt. Tamalpais form the Marin Peninsula. The Sonoma Mountains separate the Petaluma and Sonoma Valleys, and the ridge consisting of Mt. Hood and Mt. Veeder divide the Sonoma Valley from the Napa Valleys.

The Diablo Range runs along the east of San Francisco Bay and includes Mt. Hamilton, 4,213 feet (1284 m), and Mt. Diablo, 3,849 feet (1173 m). North of Benicia into Napa, the hills turn northwest and become part of the Mayacmas Mountains, with Mt. St. Helena, at 4,343 feet (1324 m), being the northern tip and the highest point of the watershed.

Among the Coast Ranges lie a series of intermountain valleys. The San Francisco Bay is the largest of these valleys. It is a late *Pliocene* structural depression submerged by rising seas. As a result of tectonic activity, the geology of the watershed is complex and unsettled. Land formations in the watershed are about 12 million years old and the shape of the present Bay developed only in the past half a million years.

The older bedrock complex comprise of the *Franciscan Formation* that includes massive and thick-bedded sandstones, shale, thin-bedded fine-grained sandstones, chert, green-stones, and metamorphic rocks. The bedrock exhibits a high degree of faulting and shearing due to crustal movement. There are three major faults passing through the watershed: the San Andreas Fault, the Hayward Fault, and the Calaveras Fault. Unconsolidated deposits made up of dune sand and water-laid sand, mud and clay overlie the bedrock. Deposits are generally 500 to 1,000 feet (150 to 300 m) thick but can be more than 3,000 feet (900 m) thick in some areas.

1.3.d Vegetation

Four major vegetative cover types occur in the watershed: coniferous forest, hardwood forest, chaparral and grassland. The distribution varies with soil, precipitation and other physical conditions. In general, the coniferous forests (mostly coastal redwood and Douglas fir, with some Ponderosa pine) are located along the Coast Ranges in southern San Mateo County and on the ridges of Marin County.

The hardwood forests are located in the drier areas of the watershed such as the Santa Clara Valley. These forests consist of tan oaks, madrones, California Laurels and eucalytus. These forests also consist of riparian woodlands made up of cottonwoods, alders, willows and sycamores.

Chaparral is a dense growth of shrubs. It is found throughout most of the watershed as pure stands or as undergrowth in forests. Chamise is usually the dominant species, with some oaks, manzanita, poison oak and sage. Grasslands also occur throughout the watershed and are composed of wild oats, brome grasses, and clovers.

1.3.e Climate

The San Francisco Bay watershed receives 90 percent of its precipitation during the six month wet period of November through April, with December, January and February receiving the heaviest precipitation. The average annual precipitation ranges from 14 inches (36 cm) in San Jose in the south to over 40 inches (100 cm) in Kentfield in the northwest.

The prevailing wind direction in the San Francisco Bay Area is on-shore from the Pacific Ocean towards the East Bay and up into the Central Valley through the delta (west to east), with smaller fractions blowing north towards Napa and Sonoma Valleys and south towards Santa Clara Valley. At certain times, more significant percentage of the winds coming through the Golden Gate also blows southerly and northerly towards Marin.

1.3.f Biology

The San Francisco Bay system, with its areas of deep water adjacent to large expanses of shallow water, tidelands, marshlands, streams and rivers, provides a wide variety of habitats making it the most significant estuary in California. It provides a migratory pathway for anadromous fish and is a key stopping point for migratory birds on the Pacific Coast Flyway.

The anadromous fish that use the Bay include Chinook and coho salmon, steelhead, striped bass, sturgeon and American shad. Other fish found in the Bay include sole, halibut, flounder, turbot, sanddabs, sharks, skates, rays, surf perch and croakers. The Bay is a nursery for Dungeness crab, and supports commercial bay shrimp and Pacific herring harvesting. The Bay also supports colonies of clams and oysters that in some areas of the Bay are being crowded out by invasive species such as the Asian clam. There are over 75 species of aquatic birds that reside or visit the watershed. The majority are ducks that feed on alkali bulrush or invertebrates in the shallow waters.

1.3.g Population/Human Alterations

Humans also inhabit the watershed to the tune of 6.5 million. Over the past 150 years, they have drastically changed the landscape. The surface area of the Bay system has shrunk by diking of marshlands for salt evaporation ponds and hay fields. The San Francisco Estuary Project estimates that greater than 80 percent of the wetlands that existed before 1850 has been lost to filling and diking. Urban development, primarily concentrated along the Bay's west, south and east shores cover roughly 20 percent of the land area. The Association of Bay Area Governments estimates that the population may grow to 8 million by the year 2020.

Aside from sand, gravel, rock, clay and salt, the other major material mined from the watershed is mercury. Mercury is available in varying amounts in all nine counties except San Francisco. Mercury deposits are usually associated with silica carbonate rocks of the *Franciscan Formation*. Two important mercury mining areas are the New Almaden district in southwestern Santa Clara County and the Petaluma District west of Petaluma (Figure 5, Table 1). The mines in the New Almaden district were the largest producers of mercury in North America. They operated on and off from the time of the California gold rush until about the late 1960's. These mining operations have impacted Bay water quality. Sediments from the southern most portion of San Francisco Bay show higher levels of total mercury as compared to other parts of the Bay (SFEI 1997)

Section 1.3 Key Points:

- The San Francisco Bay system is a large and complex estuary heavily influenced by exchange of tidal waters and outflows from the Central Valley
- The landscape of the watershed is dominated by the Coastal Ranges. Its primary geologic formation is the *Franciscan Formation*, and three major seismic faults influence the topography.
- The vegetation consist of coniferous and hardwood forests, chaparral, and grasslands
- The climate is semi-arid with 90 percent of the precipitation from November to April. Winds are primarily on-shore from the Pacific Ocean.
- Because of the variety of habitats, the Bay system is host to a large variety of aquatic organisms, several of which are commercially important.
- The watershed is a stopping point for migratory birds on the Pacific Coast Flyway
- Human habitation of the watershed has drastically changed its landscape: 80 percent of bay wetlands have been filled or diked, and 20 percent of the land has been developed for urban use.
- Historic mining of mercury, particularly in the southern part of the watershed has contributed to elevated levels of mercury in the south bay sediments.

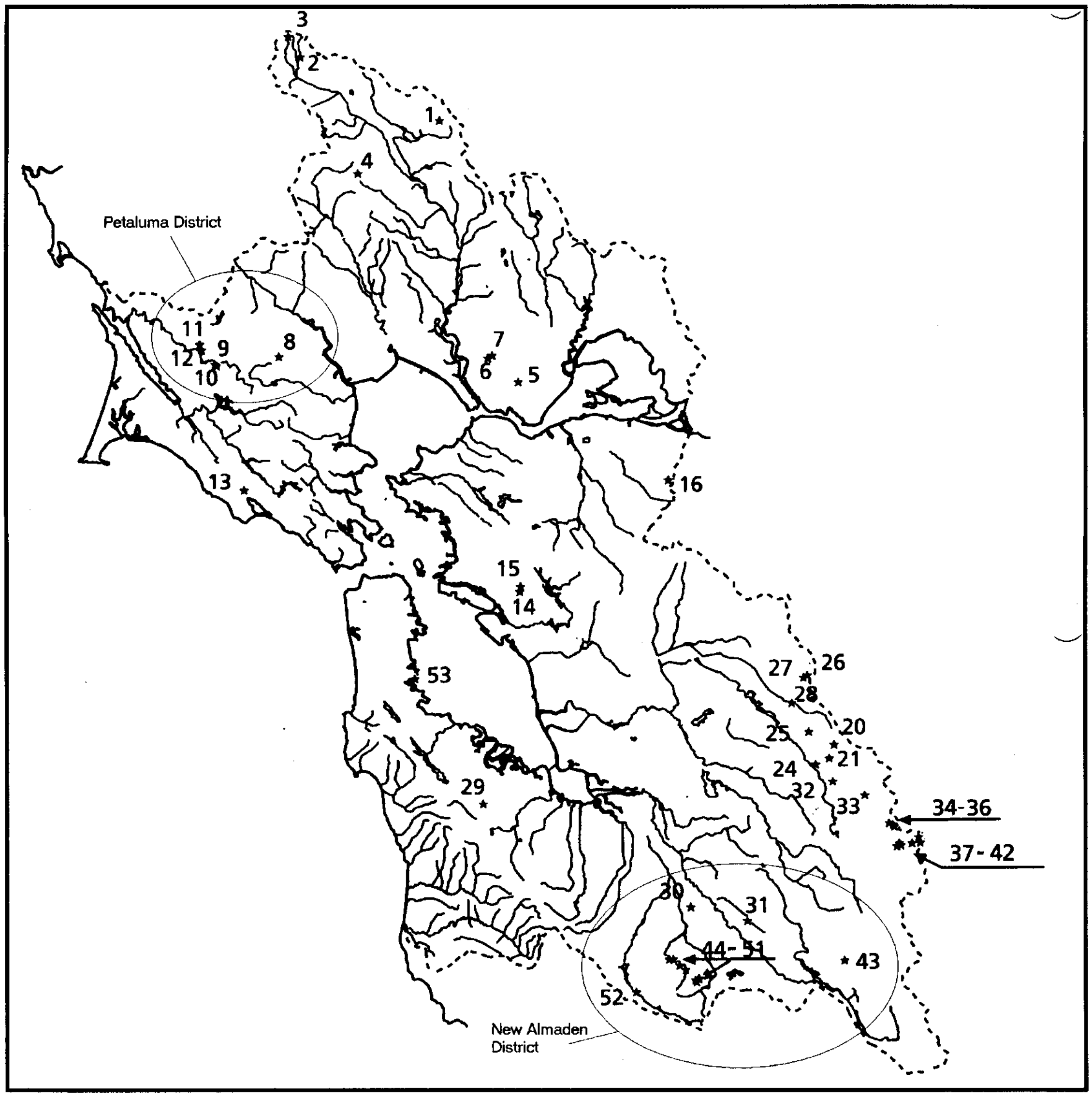


Figure 5: Locations of inoperative mines in the San Francisco Bay Region.

#	Mine	Associated Mineral	#	Mine	Associated Mineral
1	Snowflake	magnesite	30	Hillsdale	mercury
2	Palisade	silver	31	Silver Creek	mercury
3	Silverado	silver	32	Winegar	manganese
4	La Joya	mercury	33	Fable Manganese	manganese
5	Hastings	mercury	34	Western	magnesite
6	St. John's	mercury	35,36	Maltby	magnesite
7	Borges	mercury	37	Keller	magnesite
8	H. Corda	mercury	38	Queenbee No. 1	manganese
9	Cycle	mercury	39	Blackhorse	manganese
10	Franciscan	mercury	40	Black Eagle	manganese
11	Chileno Valley	mercury	41	Jones Group	manganese
12	Gambonini	mercury	42	Mexican Deposits	manganese
13	Union Gulch	copper	43	Pine Ridge	manganese
14	Leona Heights	silver	44	April	mercury
15	Alma	silver	45	Cristobal	mercury
16	Black Diamond	manganese	46	San Francisco	mercury
20	Buckhorn	manganese	47	San Pedro Pit	mercury
21	Man Ridge	manganese	48	Enriquita	mercury
24	Section 14	coal	49	San Mateo	mercury
25	Newman	chromite	50	Senator	mercury
26	Livermore Coal	coal	51	Guadalupe Mines	mercury
27	Pendarin	coal	52	Hooker Creek	copper
28	Camp 9	manganese	53	Marine Magnes Div.	magnesium salts
29	Challenge	mercury			

Table 1: Map key to Figure 5.

2. Problem Statement

2.1 Waterbody name and location

The San Francisco Bay estuary, often called the Bay or San Francisco Bay, consists of the following water bodies (starting from the north):

- Sacramento/San Joaquin River Delta
- Suisun Bay
- Carquinez Strait
- San Pablo Bay
- Central San Francisco Bay
- Lower San Francisco Bay
- South San Francisco Bay (including the Lower South Bay)

These are shown in Figure 6. For the purposes of this TMDL report, the Delta includes only the western most extreme that is downstream of Sherman Island, within the Region 2 boundary. In fact, the Delta extends eastward into the Central Valley Region (Region 5).

San Francisco Bay is a natural embayment in the Central Coast of California that has been described as "one of the most impacted estuaries" in the National Estuaries Program [3]. The impacts date back 150 years to the California Gold Rush, when hydraulic mining and dredging substantially altered the bathymetry and geochemical cycles of the estuarine system [4]. While still rebounding from those historic perturbations, the Bay is now being impacted by a surrounding metropolitan population of approximately 6.5 million people, burgeoning residential, agricultural, and industrial development, and natural weathering processes throughout its drainage basin. Therefore, an understanding of the historic and physical setting of this complicated estuary is required to put historic and contemporary anthropogenic mercury loadings into perspective.

The estuarine system is divided into two major hydrographic regions, the northern reach and the southern reach, that are linked by the central bay to the Pacific Ocean (Figure 6). The northern reach is seasonally well-flushed by fluvial discharges, because more than half of California's freshwater discharges through Sacramento and San Joaquin Rivers to the Delta. Approximately 90% of this flow occurs between November and April. This freshwater discharge replaces the volume of the northern reach every 1-60 days, depending on flow conditions. In contrast, direct fluvial discharges to the southern reach (South Bay) are negligible, because it is cut off from Central Valley drainage by the Diablo Range; the water replacement time in the lagoon-like South Bay ranges from 120 to 160 days or more [5 6 7]. Consequently, there are marked disparities in the concentrations and cycles of pollutants between the two regions of the estuary [8].

San Francisco Bay is a broad, shallow, turbid estuary. Its average depth of 6 meters (Table 2) makes resuspension of bottom sediments a dominant process in the fate and transport of pollutants[9 10 11]. Sediment resuspension is driven by several factors, including the daily tides, the spring-neap tide cycle, and seasonally variable wind patterns [12]. The complex, superimposed processes affecting sediment dynamics make modeling pollutant fate extremely challenging.

The Bay supports a variety of beneficial uses defined in the Basin Plan (Table 3). Problems associated with mercury contamination result from bioconcentration in the food chain. Human and wildlife endpoints are therefore primarily related to consumption of contaminated fish. The beneficial uses primarily threatened by mercury contamination are sport fishing (COMM), preservation of rare and endangered species (RARE), and wildlife habitat (WILD).

Section 2.1 Key Points:

- San Francisco Bay is one of the most impacted estuaries in the National Estuaries Program.
- Impacts date back to the gold rush, and include dredging, filling of wetlands, diking, and massive sedimentation from hydraulic mining.
- The Bay is currently surrounded by a burgeoning residential and industrial development.
- The Bay is divided into two distinct regions: the northern reach and the southern reach.
- The northern reach is seasonally flushed by the Sacramento River (i.e. the water has a relatively short "residence time" in winter, of around 2-14 days).
- The southern reach, in contrast, has a longer residence time of 120-160 days or more.
- The Bay is a broad, shallow, turbid estuary; sediment resuspension is extremely complex.
- Sediment transport strongly influences pollutant cycles.
- The beneficial uses threatened by mercury pollution are fish consumption, preservation of rare and endangered species, and wildlife habitat.

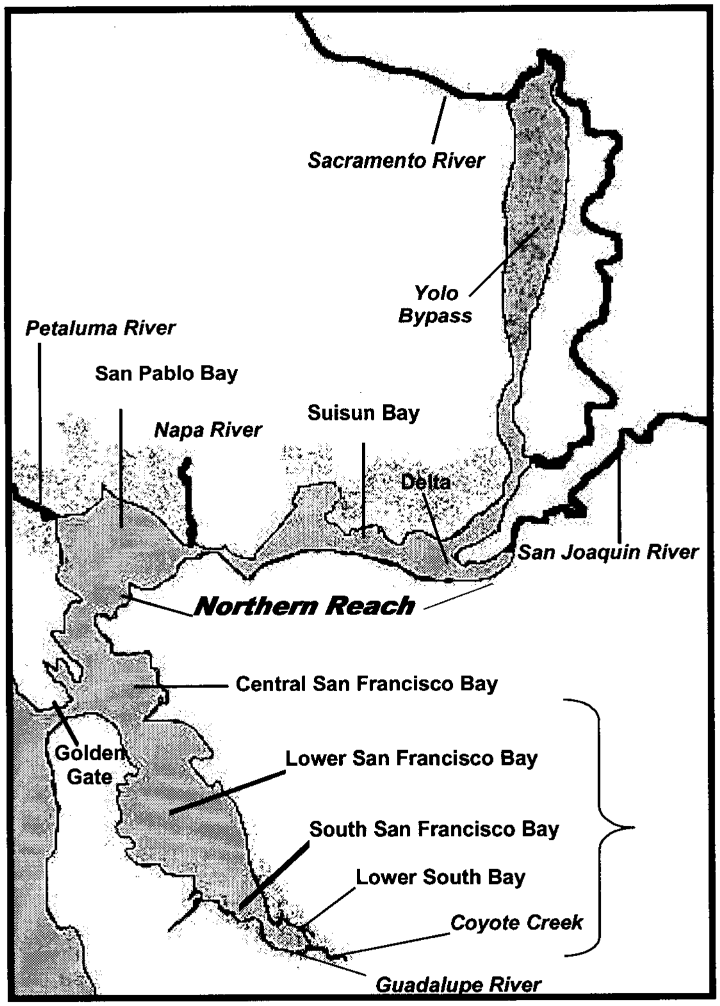


Figure 6: Map of San Francisco Bay estuary showing the locations of significant water bodies.

Statistic	Value
Area (at mean lower low water)	1.04×10^9 m^2
Including mudflats	1.24×10^9 m^2
Volume	6.66×10^9 m^3
Tidal Prism	1.59×10^9 m^3
Average depth	6.1 m
Including mudflats	2 m
River discharge (annual)	20.9×10^9 m^3
Delta outflow	19.0×10^9 m^3
Other streams	1.9×10^9 m^3

Table 2: Geostatistics of San Francisco Bay [13;14]**.**

Beneficial Use
Agricultural Supply
Sport fishing
Estuarine habitat
Groundwater recharge
Industrial service supply
Fish migration
Municipal and domestic supply
Navigation
Industrial process supply
Preservation of rare and endangered species
Water contact recreation
Noncontact water recreation
Shellfish harvesting
Fish spawning
Wildlife habitat

Table 3: Beneficial uses of San Francisco Bay defined in the Basin Plan. Beneficial uses most likely to be impaired by mercury contamination are italicized.

2.2 Water Quality and 303(d) status

The bases for CWA 303(d) listing of San Francisco Bay as impaired due to mercury vary slightly for the different Bay segments but generally can be described by the conditions:

i) consumption of fish caught from the Bay have mercury levels that may threaten human health; and

ii) concentrations of total recoverable mercury in water particularly in the Lower San Francisco and South San Francisco Bay, exceed the Basin Plan numeric objective of 0.025 µg/L.

Data brought to our attention by the U.S. Fish and Wildlife Service (U.S. FWS) have also revealed links between mercury impairment and endangered wildlife in the Bay Area.

2.2.a Mercury Levels in Fish

The California Office of Environmental Health and Hazard Assessment (OEHHA) has issued an interim fish consumption advisory for all of San Francisco Bay, based in part on mercury concentrations in fish caught in the Bay. Much of that data came from an RMP study of contaminants in fish [15]. The OEHHA advisory has been listed as interim because more information is needed, both about mercury levels in fish in San Francisco Bay and mercury levels in fish that are protective of human health. The interim advisory states the following:

- Adults should eat no more than two eight-ounce meals per month of San Francisco Bay sport fish, including sturgeon and striped bass caught in the Delta.
- Adults should not eat any striped bass over 35 inches.
- Women who are pregnant or may become pregnant, nursing mothers, and children under age six should not eat more than one meal of fish per month, nor should they eat any striped bass over 27 inches or any shark over 24 inches.
- No one should eat any croakers, surf perches, bullheads, gobies or shellfish taken within the Richmond Harbor Channel area because of high levels of chemicals detected there.
- The advisory does not apply to salmon, anchovies, herring, and smelt caught in the Bay; other sport fish caught in the Delta or ocean; nor commercial fish.

Human consumption of mercury-contaminated fish is a concern because methylmercury, the primary form of mercury in fish, is a potent neurotoxin [16 17 18]. Consumption of contaminated fish can cause blindness, paralysis, gingivitis, loss of muscular control, birth defects, and death, as evidenced by the Minamata Bay tragedy [19 20]. It must be emphasized that the best available evidence shows that threats to human health in San Francisco Bay are much less dire than other instances of mercury contamination, such as the disaster at Minamata Bay, Japan. Mercury-poisoned citizens of Minamata Bay were consuming fish with concentrations up to 50 µg/g. Those fish were contaminated as a result of extremely high concentrations of mercury, including methylmercury, discharged from an essentially uncontrolled industrial source. In San Francisco Bay, the highest mercury level measured in the 1997 RMP study[15] was 1.2 µg/g, and there is no clear evidence at present linking those fish tissue concentrations to effluent discharges in San Francisco Bay, which are several orders of magnitude lower in concentration (0.003 to 0.050 µg/L) than the discharges at Minamata Bay. To date, there is no evidence of acute or chronic mercury toxicity in San Francisco Bay Area residents.

Nonetheless, effects from long-term exposure to mercury from consumption of fish remain a concern. The issue is whether this exposure over a lifetime leads to impaired health, diminished mental performance, or higher risks of birth defects in human populations. We don't have firm answers to that question at present. The National Academy of Sciences (NAS) has convened a Committee on the Toxicological Effects of Mercury to review all of the relevant science literature and evaluate the adequacy of U.S. EPA's reference dose. When that committee report is released, extant fish consumption guidelines may be revised. The ongoing uncertainty regarding safe dietary exposure limits for mercury is one of the reasons that a phased TMDL is needed. We have to establish a TMDL using the current guidelines, and be prepared to revise the TMDL if those guidelines change.

The RMP conducted a fish tissue survey in 1994, and again in 1997[15]. The locations where fish were collected are shown in Figure 7. The species sampled, their diets, and their movements are shown in Table 4. In all, 84 composite samples representing seven species of fish were analyzed in the 1997 study. Individual striped bass were analyzed in addition to composite samples.

To assess fish tissue concentration in San Francisco Bay, SFEI developed a screening level of 0.23 µg/g in accordance with U.S. EPA guidance [21]. Exceedance of this screening value does not mean that human health is threatened, but only that further monitoring and analysis is warranted. The U.S. Food and Drug Administration (FDA) action level of 1 µg/g is the most often cited regulatory guideline for protection of human health. The FDA advises that fish with mercury concentrations in excess of 1 µg/g should not be consumed.

Half of the fish from San Francisco Bay that were analyzed for mercury showed concentrations above the screening value of 0.23 µg/g (Figure 8). Several leopard sharks exceeded the FDA action level (1 µg/g), and individual striped bass samples showed concentrations as high as 0.9 ppm (Figure 8). The overall average concentration of mercury in fish caught in San Francisco Bay is 0.3 ppm, one-third of the FDA action level. While we are not faced with a public health threat comparable to the tragedy of Minamata Bay, Japan, the mercury levels in fish caught in San Francisco Bay support the posting of fish consumption advisories as a precautionary measure and continued monitoring to determine where the most serious mercury bioaccumlation problems occur and what can be done to prevent them.

For some species (e.g. white croaker, leopard shark, jacksmelt), there is a clear relationship between fish length (a proxy for age) and tissue concentration (Figure 9). That observation is consistent with previously published accounts[22], and indicates that fish accumulate mercury body burdens as they grow. This is the basis for OEHHA's inclusion of a size limit in their consumption advisory for striped bass.

Individual striped bass show a particularly interesting size-concentration relationship (Figure 10). There appears to be two groups, one with a high slope, one with a lower slope, suggesting different exposure levels either through spatial, dietary, or other differences. The data set is too small to draw any firm conclusions, but clearly indicates the need to better understand the factors contributing to mercury accumulation in fish.

The possibility of different exposure levels indicates another challenge to assessing impairment with the current data set. All of the fish in the RMP study can spend at least a portion of their lives outside the Bay, so it is not clear where they actually picked up their mercury body burdens. One of the information needs identified in the discussion of numeric targets (Section 3) is a tissue target based on resident, sedentary species, to help identify whether spatial exposure gradients exist within the Bay.

Stakeholders have voiced concerns about environmental justice. If legacy pollution or contemporary discharge leads to increased mercury levels in fish, then the burden of impacts of is unfairly placed on subsistence fishers, who are largely lower income families, recent immigrants and people of color. To ensure that subsistence fishers are protected, we need to develop a target for mercury concentration in fish that accounts for the amounts and types of fish being caught and eaten in the San Francisco Bay.

The fish consumption advisory and measured fish tissue concentrations in fish caught in San Francisco Bay are only part of the finding of impairment. The other reason is that the Basin Plan Water Quality Objective of 0.025 μg/L is regularly exceeded in Bay waters. This objective is regularly exceeded is a direct consequence of widespread sediment contamination by mercury remobilized during and after the Gold Rush.

Key Points from section 2.2.a:

- OEHHA has issued an interim fish consumption advisory for San Francisco Bay based in part on mercury levels in fish.
- The Beneficial Use of sport fishing (COMM) is not being attained.
- Impairment of fishing raises environmental justice issues
- The FDA recommends against consumption of fish with mercury concentrations greater that 1 μg/g.
- The overall average concentration of mercury in San Francisco Bay fish is 0.3 μg/g.
- Leopard sharks frequently have concentrations exceeding 1 μg/g.
- Striped bass have concentrations approaching 1 μg/g.
- RMP data substantiate the need for further monitoring and assessment.
- RMP data also show that while mercury levels in fish may be elevated, fish caught in San Francisco Bay have not reached the disastrous mercury levels once found in Minamata Bay.
- Age-size relations in striped bass indicate the possibility of high-exposure and low-exposure subgroups.
- The OEHHA advisory is interim, and may be subject to revision if limits for safe dietary exposure change.
- The interim nature of the advisory and the information gaps about mercury levels in fish necessitate a phased TMDL approach.

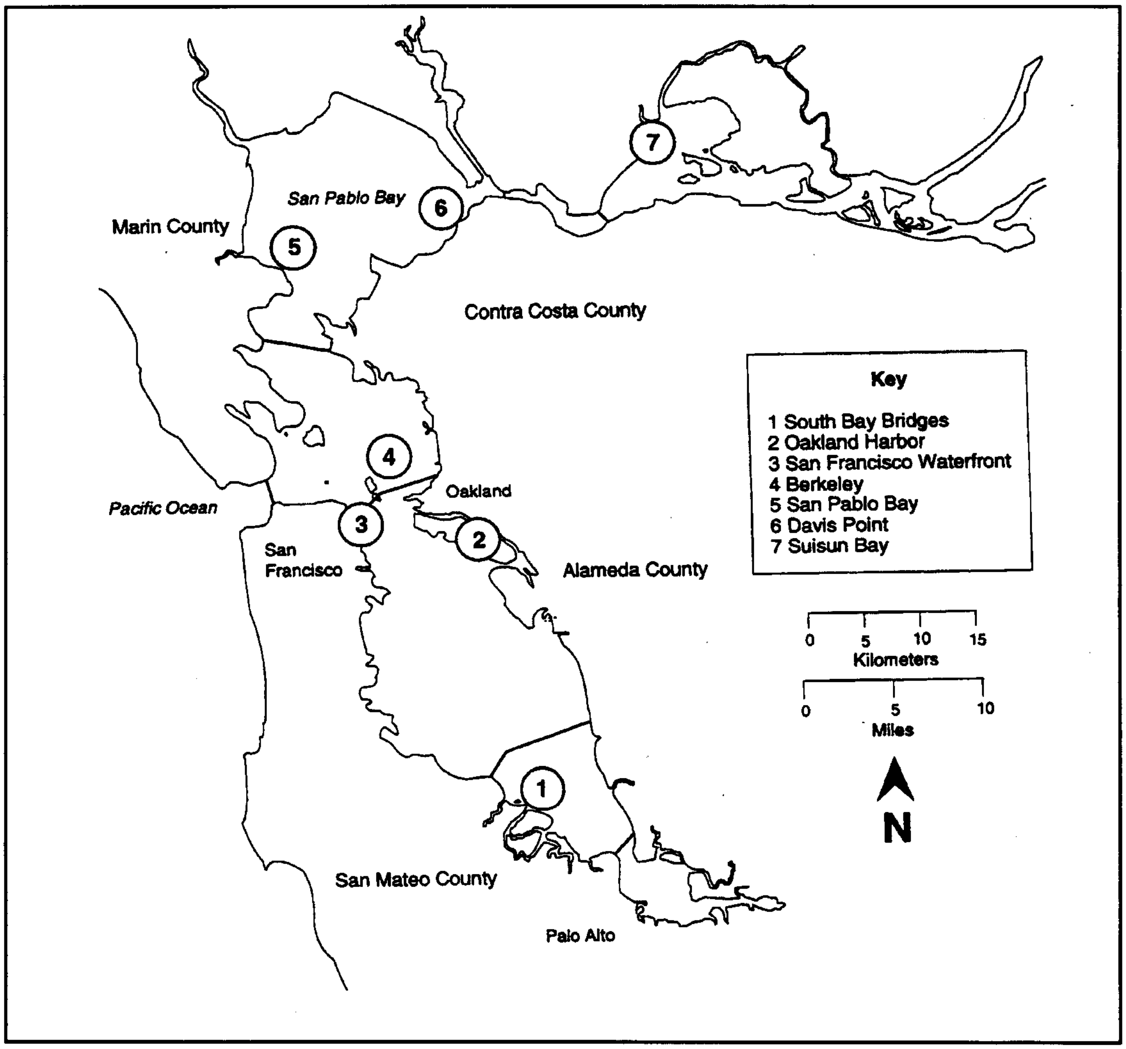


Figure 7: Map of fish sampling locations in the RMP fish tissue survey. Image taken from SFEI Report on Contaminant Concentrations in Fish from San Francisco Bay [15].

Species	Adult Diet	Movements in the Bay/Delta	Approximate age of fish caught in RMP sampling	References
California halibut (*Paralichthys californicus*) 	Pacific sardine, northern anchovy, white croaker, topsmelt, killifish, CA market squid, crustaceans	Coastal, but adults also occur in SFB year-round. Spawn in coastal waters year round in southern California, but near SFB from Jan–July. Male juveniles may stay in the Bay until they reach ~200mm; females mature later and stay in Bay longer	7–9 years	[1], [2], [3], [4], [5]
white sturgeon (*Acipenser transmontanus*) 	Fish, fish eggs (herring), shellfish, crayfish, various aquatic invertebrates, clams, amphipods, and shrimp	Spawning migration from the lower (Courtland/Freeport) Sacramento to between Knights Landing and several miles above Colusa. Many adults spend most of lives in the Estuary (even though anadromous)—primarily Suisun and San Pablo Bays	12–14 years	[4], [15], [25], [26], [27], [28], [29]
leopard shark (*Triakis semifasciata*) 	Cancer crabs, innkeeper worms, graspid crabs, squid, bay shrimp, ghost shrimp, clams, fish (such as anchovies), fish eggs, octopus spp.	Most are resident in SFB but a portion of population moves out of Bay in fall and winter. Some exchange between SFB and Elkhorn Slough populations	10–12 years	[9], [10], [11], [12], [13], [14], [15], [4]
shiner perch (*Cymatogaster aggregata*) 	Gammarid amphipods comprise bulk of year round diet in SFB, also algae, cumaceans, cyclopoid copepods, bivalve mollusks, polychaetes, smelt eggs, small shiner	Females immigrate from nearshore into SFB to give birth (live-bearers) in June or July. Males mature and emigrate soon after birth, females stay in the Bay for 1st year and give birth before 1st emigration.	Males ~3 years Females ~2 years	[4], [7], [16], [17], [18]
striped bass (*Morone saxatilis*) 	Northern anchovy, shiner perch, bay shrimp, striped bass young of the year, and herring. Diet varies greatly with location in the Bay and Delta	Spawn April-May in two areas—Sacramento River between Colusa and western Delta, San Joaquin between Antioch and Venice Island. Distribution has changed substantially in recent years. Now spend more time in Delta than Bay. Increased summer use of the ocean by adults.	Males ~4 years Females ~3 years	[4], [19], [20], [21], [22]
white croaker (*Genyonemus lineatus*) 	Wide variety of fish (mostly northern anchovy), squid, octopus, polychaetes, crabs, clams, detritus and dead organisms	Spawning occurs in the Gulf of the Farallones, and Central Bay in spring. Juveniles migrate out of the Bay in fall; re-enter and congregate in South Bay in May. Year-round adult population in deep areas of South Bay. Adults in San Pablo Bay during high salinity years.	Males ~8 years Females ~7 years	[8], [23], [24]
jacksmelt (*Atherinopsis californiensis*) 	Algae (*Ulothrix spp., Melosira monoliiformis, Enteromorpha* spp.), copepods, mysids, cirripedian nauplius larvae, small northern anchovy, gammarid amphipods, jacksmelt eggs, heteronereid polychaetes, sessile diatoms, foraminifera	Late winter/early spring immigrate from nearshore into SFB to spawn. Juveniles remain in Bay through summer then emigrate to coast in fall. During low freshwater flows use San Pablo Bay and Carquinez Strait, and in high flow years use South and Central Bay.	5–7 years	[4], [6], [7], [8]

[1] Haaker, 1975; [2] Wertz and Domeier, 1997; [3] Pattison and McAllister, 1990; [4] CA Dept. of Fish and Game Marine Sportfish webpage: http://www.dfg.ca.gov/Mrd/msfindx0.html; [5] Marine Science Institute South Bay Monitoring Program: http://www.sfbaymsi.org; [6] Clark, 1929; [7] Boothe, 1967; [8] Emmett *et al.*, 1991; [9] Russo, 1975; [10] Talent, 1976; [11] Ebert, 1986; [12] Smith and Abramson, 1990; [13] Kusher *et al.*, 1992; [14] Webber and Cech, 1998; [15] CA Dept. of Fish and Game Delta webpage: http://www.delta.dfg.ca.gov/; [16] Anderson and Bryan, 1970; [17] Bane and Robinson, 1970; [18] Odenweller, 1975; [19] Heubach *et al.*, 1963; [20] Stevens, 1966; [21] Thomas, 1967; [22] Collins, 1981; [23] Love *et al.*, 1984; [24] Herbold *et al.*, 1992; [25] Schreiber, 1962; [26] Radtke, 1966; [27] McKechnie and Fenner, 1971; [28] Muir *et al.*, 1988; [29] Schaffter, 1997.

Table 4: Summary of food habits, movements, and approximate ages of the fish species sampled in 1997. Image from SFEI Report on Contaminant Concentrations in Fish from San Francisco Bay [15].

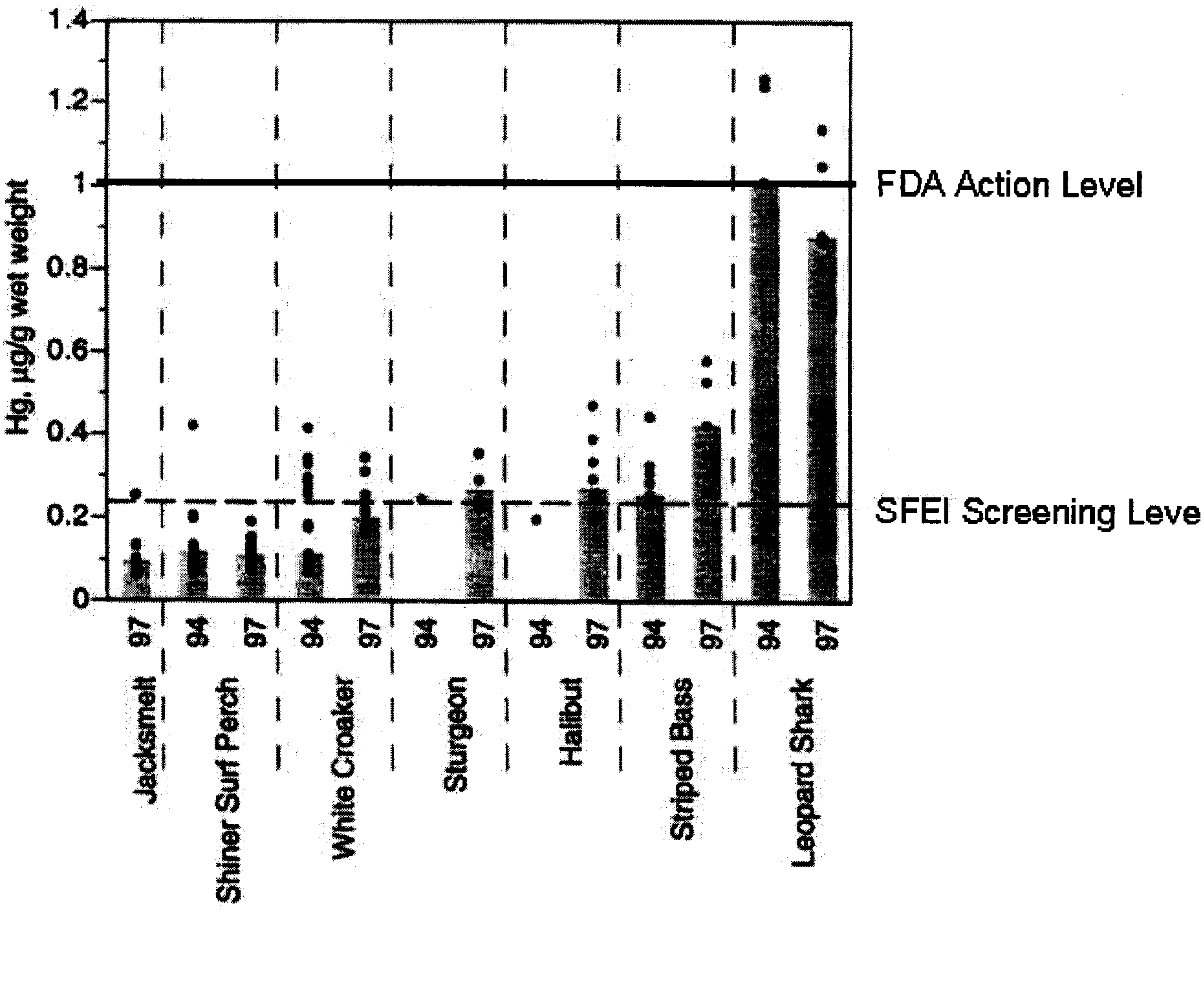


Figure 8: Mercury concentrations (µg/g wet) in Bay fish, 1994 and 1997. Points are concentrations in each sample analyzed. Bars indicate median concentrations. Dotted line horizontal indicates screening value (0.23 µg/g wet). Solid Horizontal line indicates FDA action level. Image taken from SFEI Report on Contaminant Concentrations in Fish from San Francisco Bay [15], modified by staff to show FDA action level.

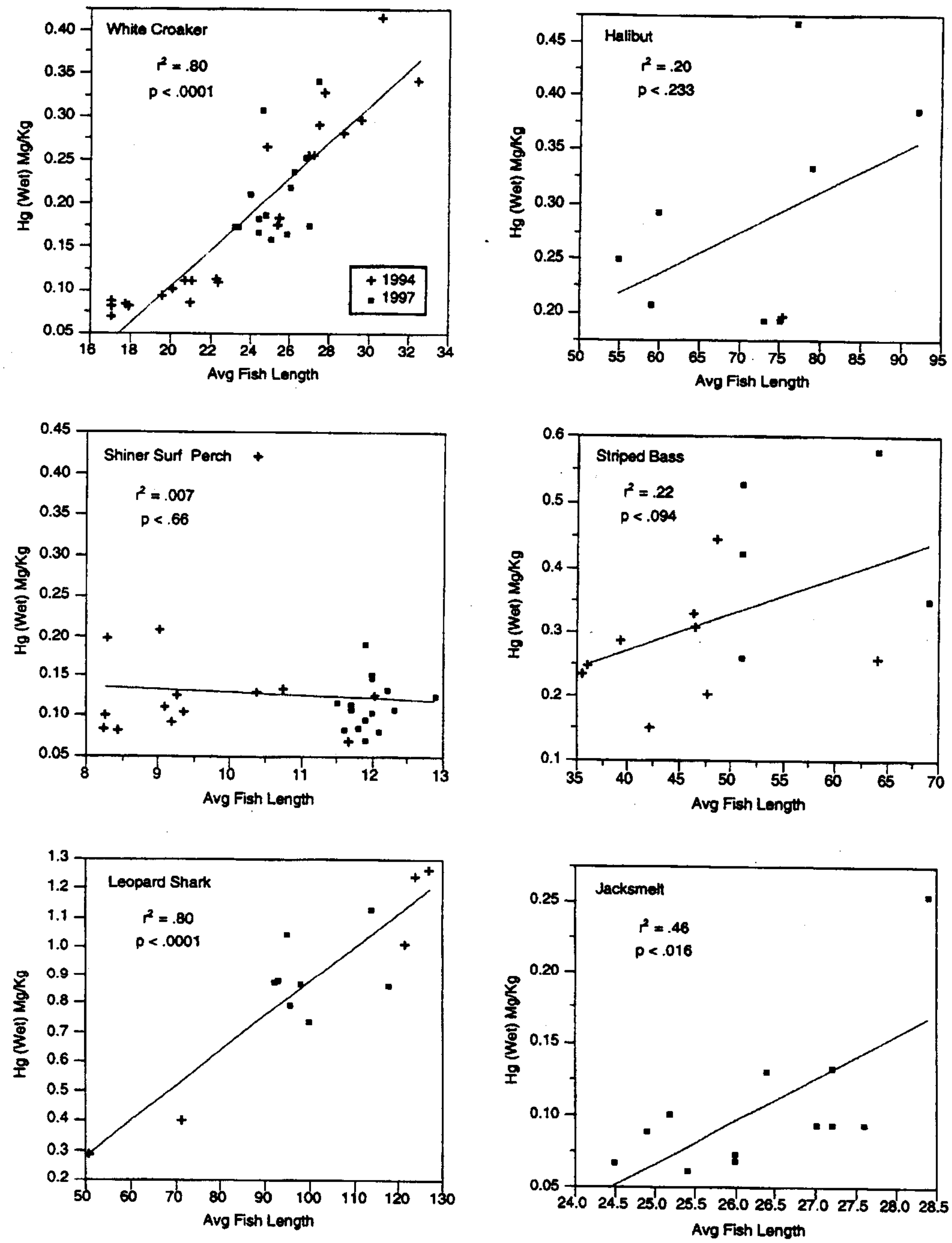


Figure 9: Regression of mercury concentrations and average fish length in composite samples for each species from the RMP, 1994 & 1997. Image taken from SFEI Report on Contaminant Concentrations in Fish from San Francisco Bay [15].

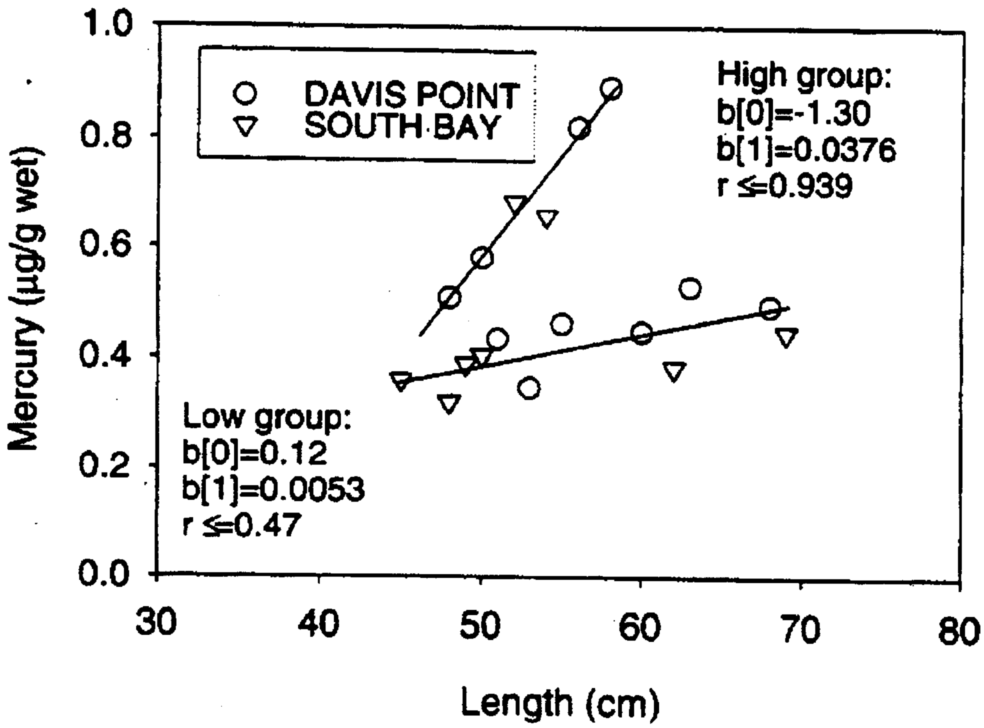


Figure 10: Regressions of mercury concentrations and fish length in individual striped bass from 1997. Image taken from SFEI Report on Contaminant Concentrations in Fish from San Francisco Bay[15].

2.2.b The Basin Plan Water Quality Objective and the California Toxics Rule Criteria

The June 21, 1995 Basin Plan is the most current Water Quality Control Plan for the San Francisco Bay Basin that is in effect. It contains a water quality objective (WQO) of 0.025 µg/L for total recoverable mercury in saltwater (total recoverable means the amount measured in an unfiltered, acidified sample). Waters south of the Dumbarton Bridge (lower South Bay) have been specifically excluded from these WQOs. However, upon final promulgation of the California Toxic Rule (CTR) by the U.S. EPA, the federal criterion of 0.050 µg/L total recoverable mercury will apply to lower South Bay. Exceedance of numeric criteria and objectives regularly occurs in most segments of the Bay, as evidenced by the data from the seventeen RMP sampling periods between 1989 and 1998[1] (Figure 11). Clearly, Basin Plan numeric objectives are not being met, despite implementation of stringent effluent limits on municipal and industrial wastewater sources throughout the region. This is because of widespread contamination of sediments in the Bay as a result of mercury mining in the Coast Range and the historic use of mercury to extract gold from placer deposits in the Sierra Nevada foothills. This is discussed in more detail in Section 2.3.

Section 2.2.b Key Points:

- The Basin Plan requires that waters north of the Dumbarton Bridge be less than 0.025 µg/L total recoverable mercury.
- The California Toxics Rule will require waters south of the Dumbarton Bridge to be less than 0.050 µg/L total recoverable mercury.
- The criteria and objectives are routinely exceeded, because of widespread mercury contamination in sediments resulting from historic mercury and gold mining activities.

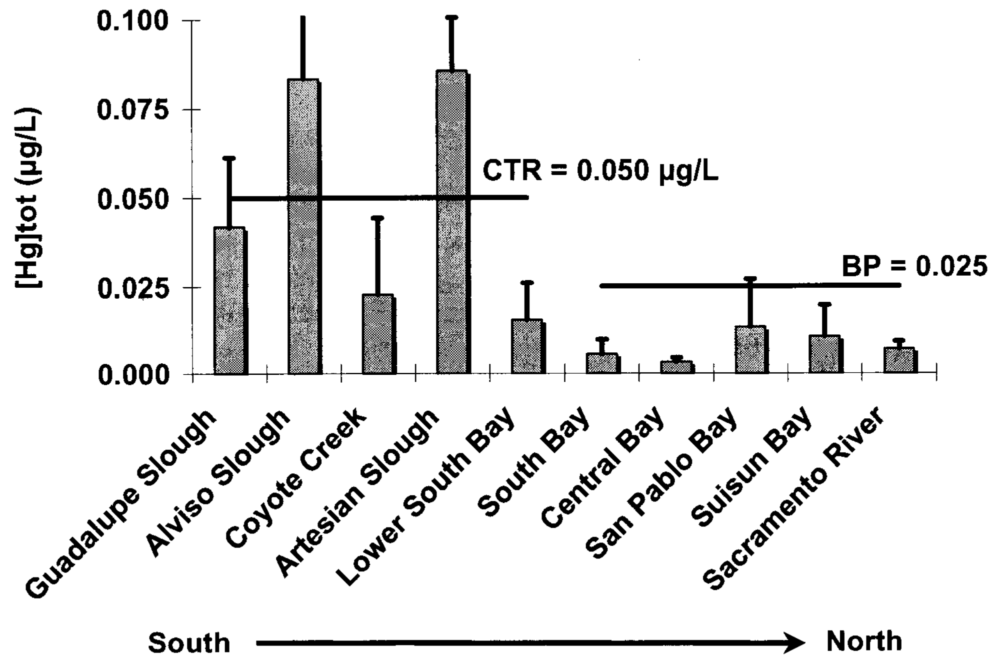


Figure 11: Exceedance of the Basin Plan water quality objective (BP WQO) and the proposed California Toxics Rule criterion (CTR HH) for protection of human health. The solid rectangles indicate the median concentrations measure by the RMP[1], 1989-1998, while the error bars indicate the upper 75'th percentile. The horizontal lines indicate the BP WQO (0.025 µg/L) or the CTR HH (0.050 µg/L). Where a rectangle is higher than a horizontal line, the criterion or objective is exceeded more than 50% of the time. Where a rectangle is below the horizontal line but an error bar crosses it, the criterion or objective is exceeded occasionally but less than half of the time. Where the entire error bar lies below the horizontal line, the objective was met at least 75 percent of the times measured from 1989-1998.

2.2.c Mercury Effects on Wildlife

Although mercury's effects on wildlife were not initially listed in the 303(d) finding of impairment, information from the U.S. Fish and Wildlife Service shows that wildlife in San Francisco Bay are threatened due to mercury pollution. The beneficial uses of the San Francisco Bay system include wildlife habitat (WILD) and preservation of rare and endangered species (RARE). Therefore, this TMDL must also address wildlife protection for developing targets and setting wasteload allocations.

San Francisco Bay is the feeding and nesting ground for multitudes of birds, both as a flyway and as a permanent home (Figure 12, Table 5). Resident species, those that obtain all or part of their diet from the Bay, are most at risk. Benthic omnivores, such as the endangered California clapper rail, forage in sediments near the oxic and anoxic interface, where methylmercury production rates are the highest[23]. Over eighty percent of the remaining California clapper rail population nests in Lower South Bay (Figure 13). The viability of clapper rail eggs in this part of the Bay is abnormally low compared to clapper rails in New Jersey [24].

Obligate piscivores, such as the endangered California least tern, feed exclusively on fish, making them vulnerable to mercury bioaccumulation. Their higher trophic position and limited foraging range mean that they could be sensitive indicators of localized impacts.

Mercury is a potent embryonic toxicant. Its concentration in avian eggs is a good indicator of reproductive success as well as the bioavailability of mercury in a system. A study by the U.S. FWS in 1982 showed that mercury in night heron eggs from the South Bay were significantly higher than heron eggs from the Gulf of Mexico and Atlantic coast locations[25]. A later study shows that there are generally higher concentrations of mercury in the eggs of waterfowl throughout San Francisco Bay compared to the same species found elsewhere in California [26]. The difference is magnified as you move up the food chain. Species affected include black-necked stilts, clapper rails, black-crowned herons, snowy egrets and least and Caspian terns Figure 14. The maximum concentrations for all of these species exceed the Lowest Observed Adverse Effect Level (LOAEL) of 0.5 mg/kg, as do most of their mean concentrations.

These concerns, show that it is important to consider effects on wildlife, especially waterfowl, when developing the TMDL. In addition to the need to protect RARE and WILD beneficial uses, protecting wildlife will benefit protection of humans. Many wildlife species get essentially all of their diet from the Bay. Consequently, they have higher exposure rates from mercury in fish than humans. A TMDL which is protective of endangered wildlife will also likely be protective of human health.

Common Name	Latin name	Foraging range	Feeding habits	status
California clapper Rail	*Rallus longirostrus obsoletus*	Salt and brackish marsh; homerange approx. 1-5 ha.	Benthic omnivore; feeds mainly on invertebrates; may feed on small rodents, fish and spartina seeds	FE SE
Western snowy plover	*Charadrius alexandrinus nivosus*	tidal zone, inter-tidal, upper tidal, along the salt marsh margins*	Marine and terrestrial omnivore	FT
California least tern	*Sterna antillarum browni*	Within approx.3.2 km of nest	Obligate Piscivore Trophic level 3	FE SE
Black-necked stilt	*Himantopus mexicanus*	salt, brackish, freshwater wetlands	Marine and freshwater aquatic invertebrates	
snowy egret	*Egretta thula*	Regional; salt, brackish, freshwater marshes and ponds	Facultative piscivore; will feed on reptiles, amphibians, and inverts	
black-crowned nightheron	*Nycticorax nycticorax*	Regional; salt, brackish, freshwater marshes and ponds	Facultative piscivore; may feed on other marine and freshwater organisms	
cormorants (Brandt's, Double-crested, and Pelagic)	genus *Phalcrocorax*	Regional; w/in few km of land on the coast; D-C may go inland	Obligate-facultative piscivore	State SC

* No data available on home range size, but likely dependent on breeding/wintering season. Breeding home range will be relatively small in the area around the nest. Wintering home range may be larger.

FE=Federal endangered
FT=Federal threatened
SE=State endangered
SC=species of special concern

Table 5: Avian wildlife threatened by mercury impairment. Data summary provided courtesy of Terry Adelsbach, U.S. FWS.

Section 2.2.c Key Points:

- The TMDL must address protection of wildlife, particularly for resident species.
- Mercury levels in eggs of waterfowl are higher in San Francisco Bay compared to other areas that do not have the same history of mining sources.
- Mercury levels in waterfowl eggs suggest impairment of reproductive success.
- A TMDL that is protective of resident waterfowl species that feed on fish will also be protective of human health.

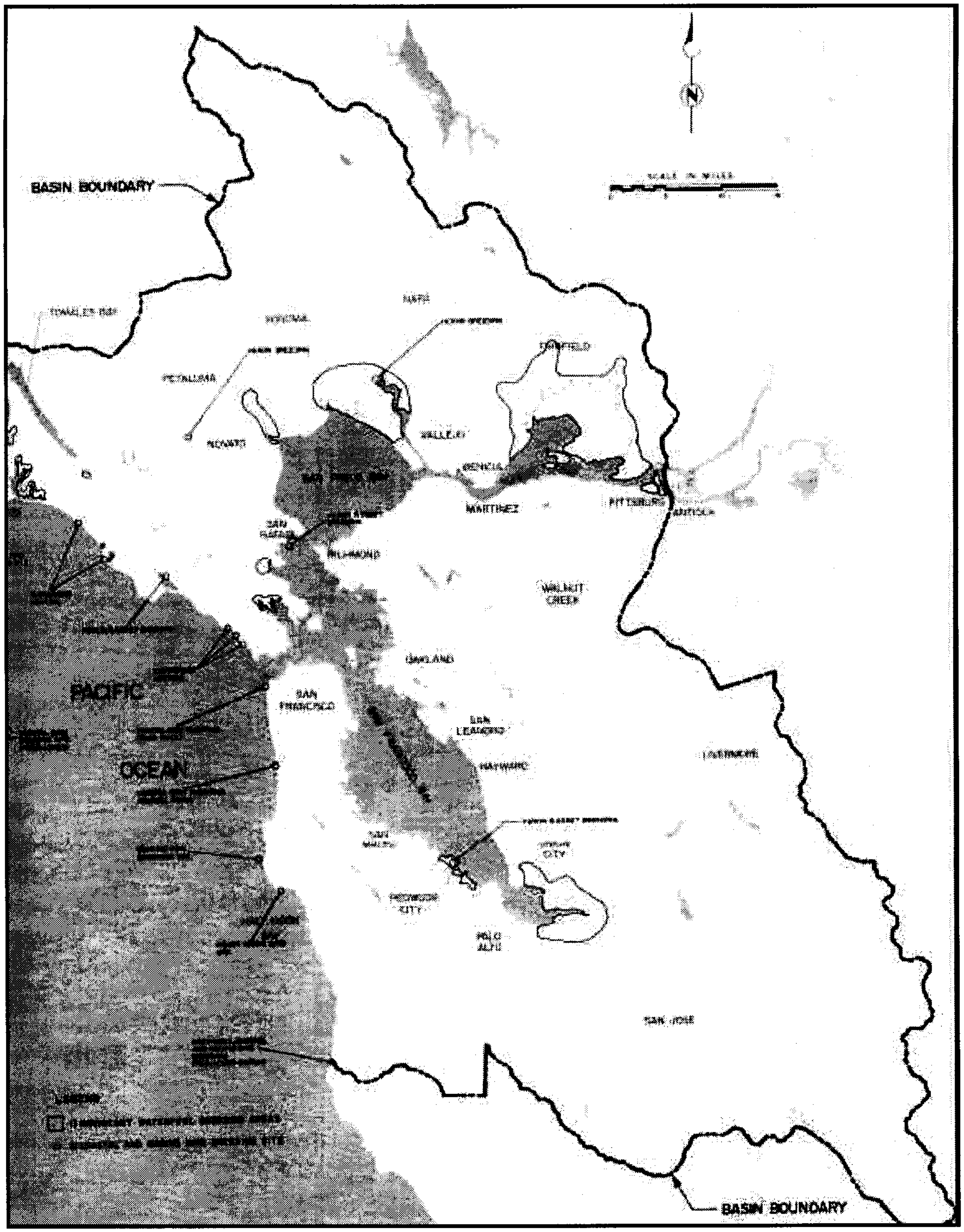


Figure 12: Waterfowl breeding sites in the San Francisco Bay Region. Taken from the 1975 Basin Plan

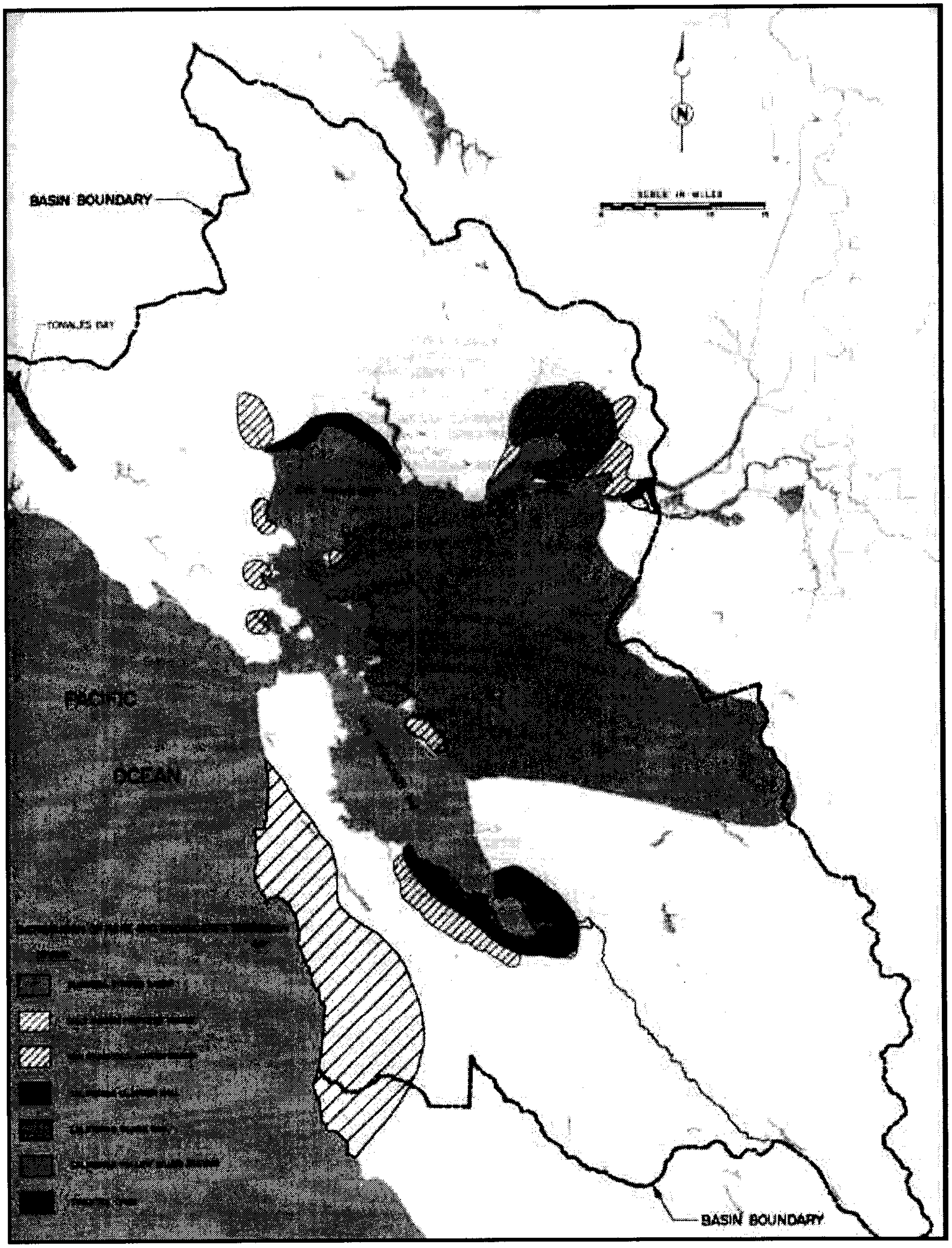


Figure 13: Distribution of rare and endangered species in the San Francisco Bay Region. Image taken from the 1975 Basin Plan.

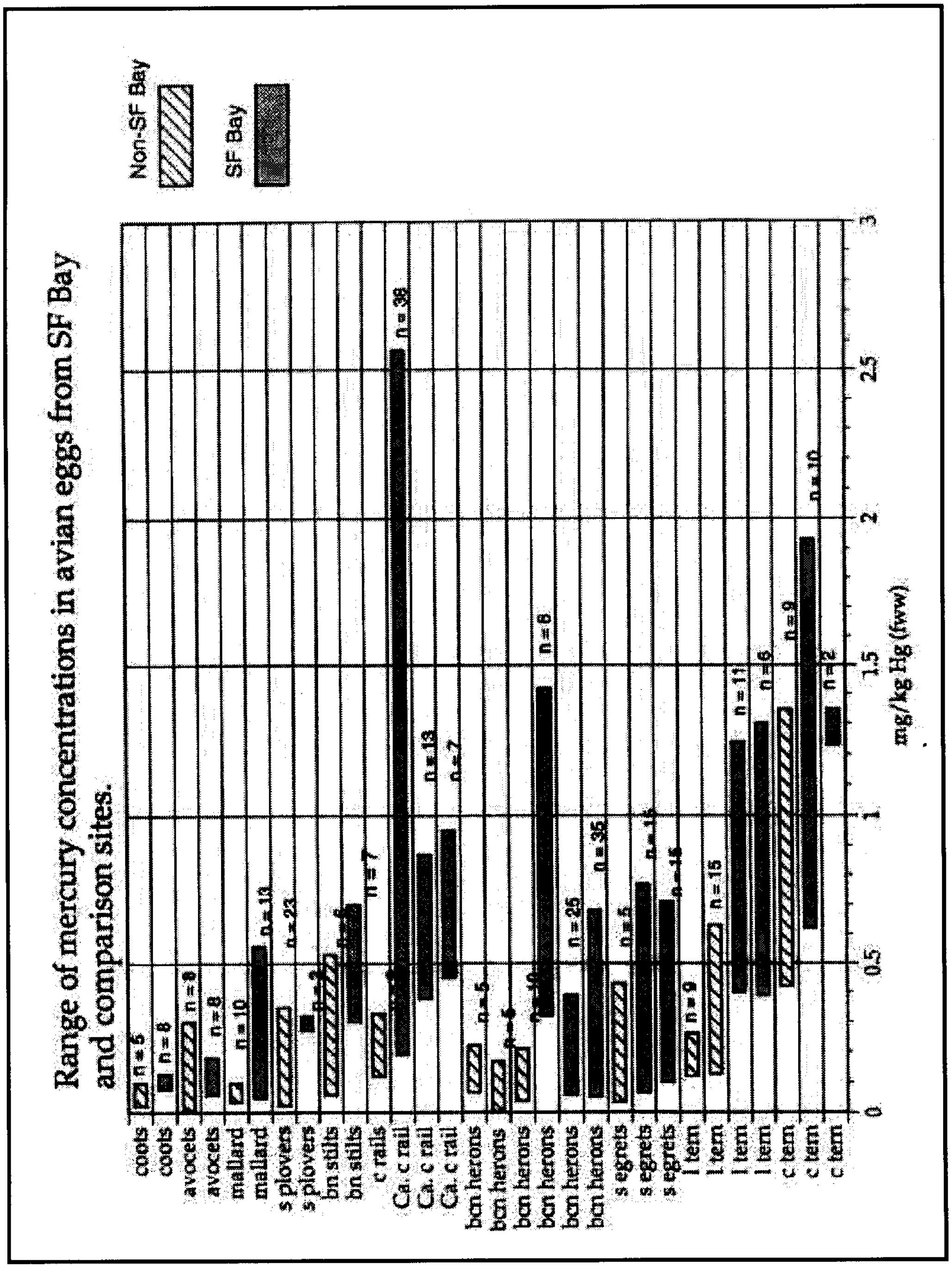


Figure 14: Comparison of mercury concentrations in avian eggs from San Francisco Bay and with avian eggs from other regions. Species are arranged in order of increasing trophic level, with coots at the lowest trophic level, and terns at the highest level. Image taken from poster abstract by Schwarzbach et. al (U.S. FWS) [26].

2.3 The mercury legacy of the California Gold Rush and the New Almaden Mine

San Francisco Bay (Region 2) is unique among the nine California watershed regions in that it has an established numeric objective for mercury in its Basin Plan, and ten years worth of monitoring data that allows evaluation of compliance with that objective. The data from the RMP afford a scientific analysis of on of the fundamental question of this TMDL: why are WQOs routinely exceeded in the Bay? This section will establish the links between exceedance of WQOs and mercury pollution resulting from local mercury mining and use of mercury amalgamation during the Gold Rush.

There is a linear relationship (Equation 1) between suspended load (TSS) and the total recoverable mercury concentration in water ($[Hg]_{tot}$).

Equation 1

$$[Hg]_{tot} = [TSS] \times [Hg]_{sed} / 1{,}000$$

$[Hg]_{tot}$ = total recoverable mercury concentration, (μg mercury / L water)
[TSS] = total suspended solids (or sediment) in (mg sediment / L water)
$[Hg]_{sed}$ = sediment concentration of mercury (μg mercury / g sediment)
1000 = conversion factor for milligrams to grams.

This relationship is apparent in a plot of $[Hg]_{tot}$ vs. TSS for over 400 samples collected throughout San Francisco Bay, 1989-1997 (Figure 15). The data do not fall exactly on a straight line because suspended sediment mercury concentrations are not the same throughout the Bay.

Mercury in the South Bay is substantially enriched compared to the northern reach. This is readily seen by separating northern reach samples from southern reach samples (Figure 16). The slope of the best-fit line in a plot of $[Hg]_{tot}$ vs. TSS gives an estimate of the average concentration of mercury in suspended particles (Equation 1). By this method, South Bay suspended sediments have mercury concentrations of ≈ 0.5 μg/g, compared to ≈0.3 μg/g in the rest of the Bay, and ≈0.2 μg/g in the Sacramento River source waters.

This spatial gradient leads to the mouth of the Guadalupe River in South Bay, as seen from a plot of suspended particulate mercury concentrations ($[Hg]_{SS}$) (Figure 17). This plot reveals the legacy of the California Gold Rush and its impacts on San Francisco Bay. Sediments entering the estuary have median concentrations of ≈0.2 μg/g, two to four times higher than pre-anthropogenic concentrations (*see below*). In Suisun Bay and San Pablo Bay, $[Hg]_{SS}$ increases to ≈0.3 μg/g. In the Central Bay and outside the Golden Gate, there is a localized peak in $[Hg]_{SS}$ of ≈ 0.5 μg/g. This is likely due to particle size-sorting over deeper areas of the Bay: fine sediments tend to stay in suspension longer, and mercury concentrations are generally higher in fine sediments. Median $[Hg]_{SS}$ values in the shallow South Bay are also ≈ 0.5 μg/g, but this is more than just a grain size effect.

Although the effect of grain size needs to be considered, the weight of evidence clearly points to a gradient leading up to the Guadalupe River mouth, where $[Hg]_{SS}$ approaches ≈0.7 μg/g.

In addition to the RMP, other near-field monitoring programs have detected mercury sediment concentrations of ≈1 μg/g in the lower Guadalupe River[27;28]. In the upper watershed, mercury in stream sediments reaches concentrations up to 168 μg/g (SCVWD 1992). Staff have collected ore-grade cinnabar and elemental quicksilver from the bed of the Guadalupe River and its tributaries by panning streambed sediments.

The source of mercury pollution in the Guadalupe River watershed is the now inoperative New Almaden mercury mining district. Once the largest producer of mercury in North America, this mine produced an estimated 38,000,000 kg of mercury from the time it was claimed in 1845 until its closure in 1975, yielding a gross revenue in excess of $60,000,000. The land, now owned by Santa Clara County, is operated as a park. Some remediation actions were taken as a result of Department of Toxic Substances Control (DTSC) concerns over human exposure. However, DTSC only required cleanup to soil levels of 100 μg/g or less, levels that are three orders of magnitude higher than acceptable for water quality. Considerable amounts of contaminated sediments and waste rock still exist on the mine site, and the sediments throughout the entire system of creeks and control structures below the watershed are enriched in mercury

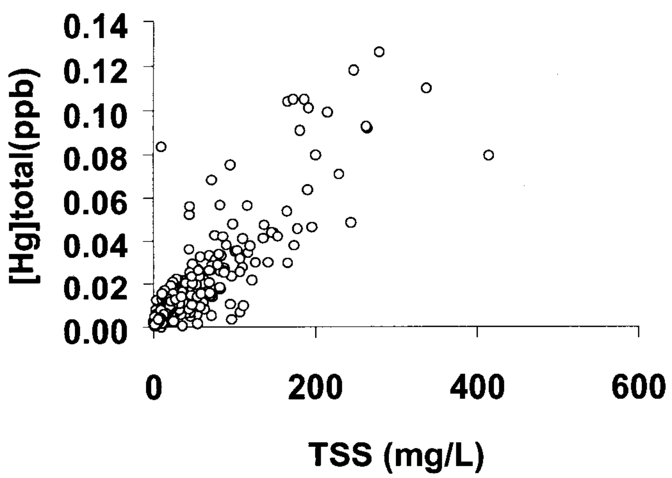


Figure 15: Plot of total recoverable mercury in water vs. TSS in San Francisco Bay 1989-1997. Data from the RMP[1] and its pilot program, including previously unpublished data by Gill and Flegal.

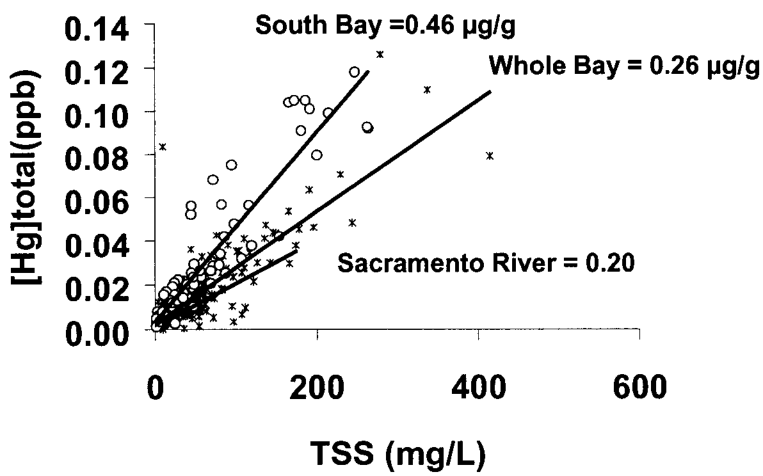


Figure 16: Plot of total recoverable mercury in water vs. TSS in San Francisco Bay 1989-1997. Data from the RMP[1] and its pilot program, including previously unpublished data by Gill and Flegal. South Bay Stations are represented by circles, the central bay and northern reach by x's. The slope of the best fit lines indicate the average concentrations of mercury in suspended sediments in each segment.

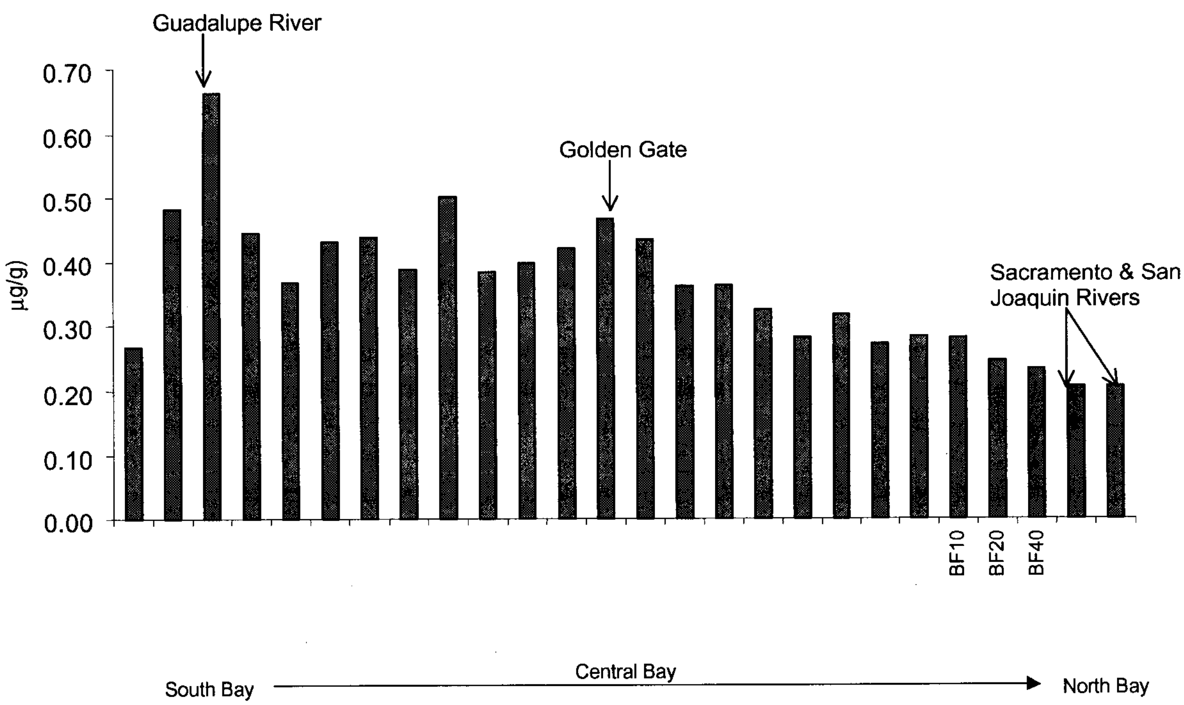


Figure 17: Median concentrations of mercury in San Francisco Bay suspended particulate matter, 1989-1997, calculated from RMP data [1]. Suspended particulate mercury concentrations calculated as ([Hg]tot – [Hg]diss)/TSS.

This has been a recognized problem for thirty years. As long ago as 1971, fish collected from Alamaden and Calero Reservoirs, below the mine, were also found with mercury concentrations up to five times higher than the FDA action level of 1 μg/g [28]. This prompted a ban in the mid-1980's on consumption of fish caught from the Guadalupe River and its reservoirs.

Some of the mercury from the New Almaden Mine is converted to methylmercury, a highly toxic and bioaccumulative form of mercury. Methylmercury concentrations in sediments from the upper Guadalupe River are almost one-hundred fold higher than baywide concentrations (Figure 18). Mercury pollution in South Bay leads to methylmercury concentrations in sediments that are several times higher than in the North Bay (Figure 19).

Comparison with sediment data from a national pilot study helps put these methylmercury concentrations into perspective (Figure 20). Concentrations from twenty-one U.S. watersheds ranged from 0.2 to 7.3 ng/g, with a median value of 1.0 ng/g. Methylmercury concentrations in the northern reach are within this range, with a median value of 0.1 ng/g, and a maximum value of 0.5 ng/g. The median of South Bay concentrations is 0.3 ng/g, higher than in the northern reach, but the maximum is still within the range of sediments from the national study. But sediments in the Guadalupe River have higher methylmercury concentrations than any other watersheds in the national study.

South Bay sediments are enriched in mercury, as a result of inputs from the Guadalupe River system. Elevated mercury concentrations in sediments cause exceedance of criteria and objectives (Figure 11). The magnitude of mercury inputs from the Guadalupe River is discussed in the Sources and Loadings Analysis (Section 4). Mercury in sediments is converted to methylmercury. The Linkage Analysis (Section 5) will show how the production of methylmercury impairs beneficial uses of San Francisco Bay.

Inputs from the New Almaden Mercury Mine are dominant in the South Bay problem definition. But what about the historic use of mercury in gold mining and other mercury mines in the Central Valley and Coast Range? The impact of those historic effects is evident from deep cores collected in Grizzly Bay and San Pablo Bay (Figure 21).

Surface sediment concentrations are ≈0.3 μg/g in both embayments, similar to suspended particulate mercury concentrations. Concentrations increase to 0.8 - 1.0 μg/g at depth, as a result of deposition of mercury-laden sediments from the hydraulic mining era[29]. Physical and biological mixing of mercury-enriched deep sediments with surficial sediments, coupled with sediment resuspension, leads to an input of mercury from historic deposits. The magnitude of this source is discussed in the Sources and Loadings Analysis (Section 4).

In the deepest portion of the cores, mercury concentrations of 0.05 to 0.1 μg/g define the range for preanthropogenic mercury in sediments. If this mercury concentration was attained in sediments throughout the estuary, the current Basin Plan objective of 0.025 µg/L would be attained in almost all of the Bay.

Mercury concentrations in sediments transported into the estuary from the Sacramento River are ≈0.2 µg/g, lower than in-Bay sediments, deep sediments, or sediments conveyed by the Guadalupe River, but still higher than pre-anthropogenic levels. The concentrations of mercury observed at the head of the estuary likely result from a superposition of atmospheric deposition throughout the greater Central watershed, inputs from inoperative coast-range mercury mines, and legacy inputs from past gold-mining operations in the Sierra Nevada foothills. The Sources and Loadings Analysis (Section 4) describes what is known about the processes leading to mercury enrichment in sediments exported from the Central Valley.

In summary, sediments polluted from the mobilization of mercury during and after Gold Rush are the primary reason that water quality objectives and criteria are exceeded. In Section 3, a target for mercury concentrations in sediment is proposed that addresses ongoing inputs of mercury-enriched sediments.

Section 2.3 Key Points:

- A decade's worth of monitoring data reveals that exceedance of total recoverable objectives and criteria for mercury is caused by mercury contamination in sediments.
- Mercury from the New Almaden Mine is conveyed by the Guadalupe River into South Bay, which is substantially enriched in mercury compared to the northern reach.
- The effect of inputs from the hydraulic mining era of the Gold Rush is also seen in the concentrations gradients in sediment cores from the northern reach.
- Methylmercury concentrations in South Bay sediments are higher than in the northern reach, but are comparable to methylmercury concentrations in other U.S. watersheds.
- Some of the highest sediment Methylmercury concentrations in the U.S. are found in the Guadalupe River.

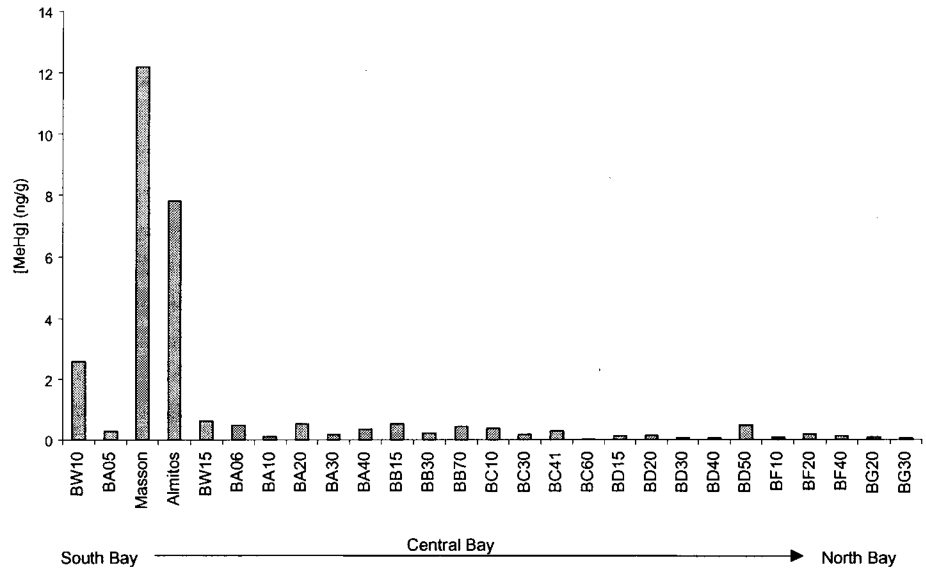


Figure 18: Methylmercury concentrations in sediments from San Francisco Bay and the Guadalupe River. Data from the RMP [1] and collaborators at United States Geological Survey, University of California Santa Cruz, and Chesapeake Biological Laboratories. RMP Samples collected July, 1999. Guadalupe River samples (Masson, Almitos) collected June, 1999.

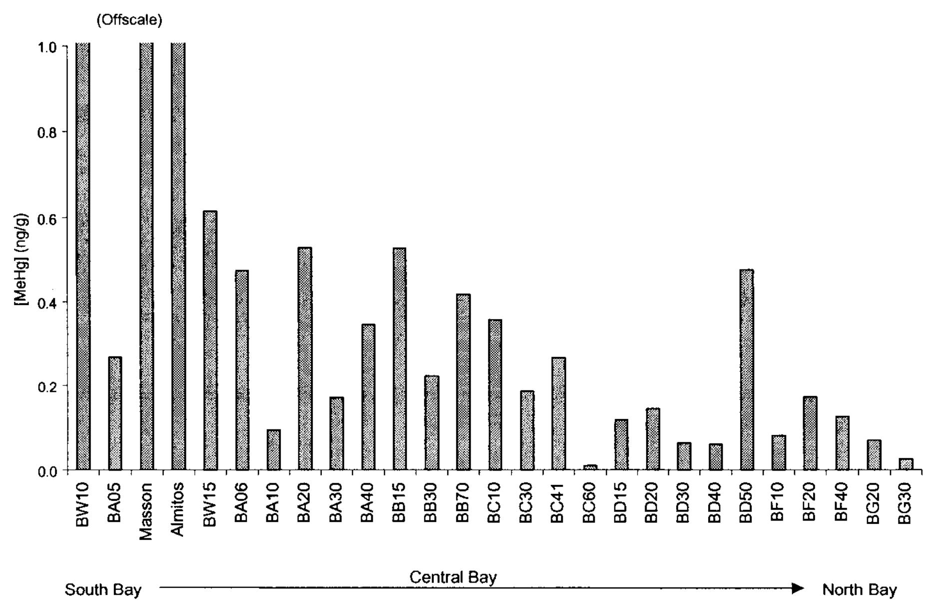


Figure 19: Methylmercury concentrations in sediments from San Francisco Bay and the Guadalupe River. Same data as Figure 18, with scale adjusted to resolve lower concentrations.

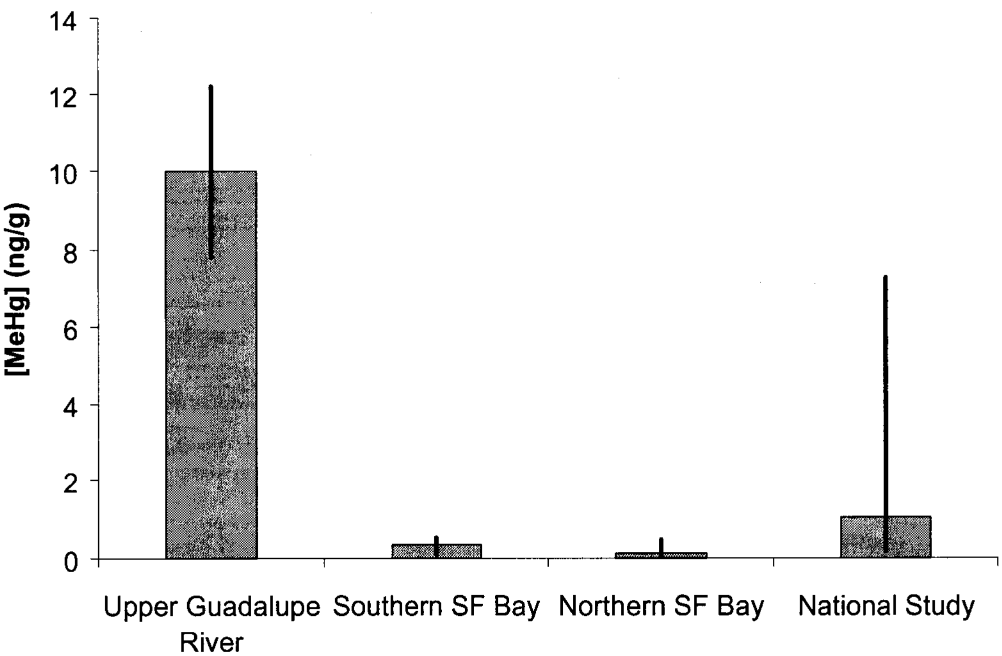


Figure 20: Comparison of sediment methyl mercury concentrations in the Guadalupe River, southern San Francisco Bay, and northern San Francisco Bay, with concentrations from a national pilot study of watersheds [30]. Solid grey bars indicate medians, heavy black lines indicate ranges.

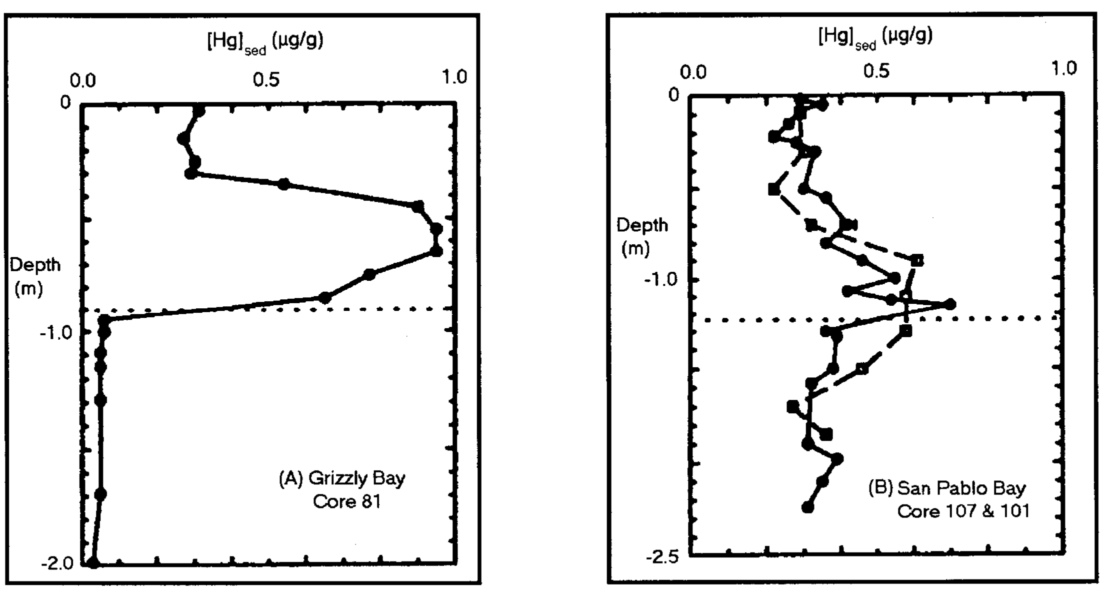


Figure 21: Sediment mercury concentrations in deep cores from (A) Grizzly Bay and (B) San Pablo Bay. Dashed horizontal line shows the maximum depth of Cs-137 penetration. Images taken from publication by Hornberger et al. (USGS)[29].

3. Numeric Targets

TMDLs are developed to meet applicable water quality standards. These may include numeric water quality criteria and objectives, narrative objectives for the support of designated uses, and other associated indicators of beneficial uses. A numeric target identifies the specific goals or endpoints of the TMDL which equate to attainment of the water quality standard. The numeric target may be equivalent to a numeric criterion or objective, if one exists, or it may represent a quantitative interpretation of a narrative objective. This section begins with a review of applicable water quality criteria and objectives and their environmental relevance. Then the importance of a sediment target in identifying ongoing sources is explained, and a sediment target is proposed. Finally, other relevant numeric targets (e.g., fish tissue concentrations, methylmercury concentrations in sediment and water) are summarized, and a target for dissolved methylmercury concentrations in water is proposed.

The numeric target for mercury concentrations in sediments is proposed based on the premise that mercury in San Francisco Bay sediments should reflect the nature of source material from the Central Valley. This target can be implemented in the first phase of the TMDL, and addresses the most immediate and obvious causes of impairment: ongoing inputs from legacy mining sources within the San Francisco Bay region.

The numeric target for dissolved methylmercury concentration in water is proposed based on the narrative objective for bioaccumulative substances. This target should be investigated further before implementing, because of ongoing uncertainties. Those uncertainties include target levels of mercury in fish that are protective of human health and wildlife, the bioaccumulation factor for methymercury in marine and estuarine systems, and the rate of methylmercury production within the Bay. However, the target can be used in a weight-of-evidence approach to establish linkages between sources and impaired beneficial uses.

Preliminary methylmercury monitoring data and the best available information for methylmercury bioaccumulation and a safe level of mercury in fish show that the actions triggered by the sediment target for mercury will be consistent with our subsequent implementation of a dissolved methylmercury target. No matter how we look at it, ongoing inputs from the Guadalupe River system and the New Almaden Mercury Mine must be controlled if we are ever going to attain standards.

3.1 Numeric Water Quality Criteria and Objectives

The Regional Board has adopted numeric water quality objectives that are applicable to all surface waters in the region and Bay waters north of the Dumbarton Bridge. Lower South Bay was exempted from numeric objectives in the Basin Plan, but upon promulgation of the California Toxics Rule (CTR), the federal numeric criteria will apply in those waters. Table 6 lists the Basin Plan objectives and proposed CTR criteria.

Water Type	Exposure	Criteria or objective (μg/L)	Reference
Salt Water	Chronic (4 –day average)	0.025	1995 Basin Plan
Fresh Water	Chronic (4-day average)	0.025	1995 Basin Plan
All	Protection of human health from exposure to water and organisms	0.051	Proposed U.S. EPA CTR

Table 6: Summary of numeric criteria and objectives applicable to San Francisco Bay. All values are total recoverable concentrations.

Total recoverable objectives are not very useful for protecting human health, because they don't address methylmercury, the form of mercury that bioaccumulates. A TMDL directed a mercury levels in fish must target methylmercury concentrations. Nonetheless, the legally valid Basin Plan objective for total recoverable mercury is a useful metric for mercury pollution, if its environmental relevance is clarified.

Waters of San Francisco Bay should not, in fact, exceed 0.025 μg/L anywhere. That they do is a result of pervasive anthropogenic pollution. This can be understood through the simple relationship between total recoverable mercury concentrations, suspended load, and mercury concentrations in suspended particles.

The concentration of total recoverable mercury in water is directly related to the amount of sediment suspended in the water, and the concentration of mercury on that suspended sediment. As discussed in the Problem Definition (Section 2) this is expressed as:

Equation 1

$$[Hg]_{tot} = [TSS] \times [Hg]_{sed} / 1,000$$

$[Hg]_{tot}$ = total recoverable mercury concentration, (μg mercury / L water)
[TSS] = total suspended solids (or sediment) in (mg sediment / L water)
$[Hg]_{sed}$ = sediment concentration of mercury (μg mercury / g sediment)
1000 = converstion factor for milligrams to grams.

Equation 1 shows how a target for mercury in sediments can be derived from the Basin Plan objectives. We cannot regulate the [TSS] in the Bay. However, it can be readily shown that if mercury concentrations in sediment were at pre-anthropogenic levels, there would be few, if any, instances where total recoverable concentrations exceed 0.025 μg/L.

We have a good understanding of how suspended sediments vary in time and space throughout the estuary, owing to a comprehensive study of sediment transport processes conducted for the RMP by the United States Geological Survey [12]. Continuous measurements of suspended sediments have been made over a six year period at several stations distributed throughout the estuary. The percentile distributions of suspended sediments are shown in Table 7.

Location	50'th Percentile of [TSS] (mg/L)	75'th Percentile of [TSS] (mg/L)	95'th Percentile of [TSS] (mg/L)
Mallard Island - Near Surface	39	51	84
Mallard Island - Near Bottom	43	62	109
Mallard Island - Near Surface	65	86	137
Mallard Island - Near Bottom	115	170	308
Martinez - Near Surface	51	69	128
Point San Pablo - Mid Depth	62	103	219
Point San Pablo - Near Bottom	77	127	260
Golden Gate Bridge, Mid-Depth	16	21	27
Pier 24 - Mid Depth	29	42	75
Pier 24 - Near Bottom	39	64	144
Channel Marker 17, Mid-Depth	101	187	404
Channel Marker 17, Near Bottom	126	245	607
Dumbarton Bridge, Mid-Depth	81	122	250
Dumbarton Bridge, Near Bottom	124	209	442
San Mateo Bridge, Mid-Depth	42	68	141
San Mateo Bridge, Near Bottom	51	84	178

Table 7: Suspended sediment levels throughout San Francisco Bay. The data next to each location specify the highest TSS values (mg sediment per liter of water) observed for the percentage of time specified in the column headers; i.e., TSS at Mallard Island near the surface is less than 39 mg/L 50% of the time, and less than 84 mg/L 95% of the time for the period measured.

Table 7 is a powerful tool for helping to understand the environmental relevance of the Basin Plan objectives. Deep core samples taken from throughout San Francisco Bay demonstrate that prior to the Gold Rush, mercury concentrations in sediment ranged from 0.05 to 0.10 µg/g [29]. Substituting those concentrations and Table 7 TSS values into Equation 1 yields the predicted baywide pre-anthropogenic distributions of total recoverable mercury (Table 8).

Table 8 shows what the bay would look like, in terms of total recoverable mercury in water, if suspended sediments were at pre-anthropogenic mercury concentrations. The Basin Plan objective would only be exceeded in the bottom waters of the most turbid regions. The reason that the surface waters in many regions today exceed that objective (Figure 11) is that sediments are two- to eight- fold enriched in mercury compared to pre-anthropogenic levels. Therefore, a target for mercury concentrations in sediments is needed to develop a TMDL that attains standards.

Location	50'th Percentile of $[Hg]_{tot}$ (μg/L)	75'th Percentile of $[Hg]_{tot}$ (μg/L)	95'th Percentile of $[Hg]_{tot}$ (μg/L)
Mallard Island - Near Surface	0.002 - 0.004	0.003 - 0.005	0.004 - 0.008
Mallard Island - Near Bottom	0.002 - 0.004	0.003 - 0.006	0.005 - 0.011
Mallard Island - Near Surface	0.003 - 0.007	0.004 - 0.009	0.007 - 0.014
Mallard Island - Near Bottom	0.006 - 0.012	0.009 - 0.017	0.015 - ***0.031***
Martinez - Near Surface	0.003 - 0.005	0.003 - 0.007	0.006 - 0.013
Point San Pablo - Mid Depth	0.003 - 0.006	0.005 - 0.010	0.011 - 0.022
Point San Pablo - Near Bottom	0.004 - 0.008	0.006 - 0.013	0.013 - ***0.026***
Golden Gate Bridge, Mid-Depth	0.001 - 0.002	0.001 - 0.002	0.001 - 0.003
Pier 24 - Mid Depth	0.001 - 0.003	0.002 - 0.004	0.004 - 0.008
Pier 24 - Near Bottom	0.002 - 0.004	0.003 - 0.006	0.007 - 0.014
Channel Marker 17, Mid-Depth	0.005 - 0.010	0.009 - 0.019	0.020 - ***0.040***
Channel Marker 17, Near Bottom	0.006 - 0.013	0.012 - 0.025	***0.030 - 0.061***
Dumbarton Bridge, Mid-Depth	0.004 - 0.008	0.006 - 0.012	0.013 - ***0.025***
Dumbarton Bridge, Near Bottom	0.006 - 0.012	0.010 - 0.021	0.022 - ***0.044***
San Mateo Bridge, Mid-Depth	0.002 - 0.004	0.003 - 0.007	0.007 - 0.014
San Mateo Bridge, Near Bottom	0.003 - 0.005	0.004 - 0.008	0.009 - 0.018

Table 8: Predicted total recoverable mercury in San Francisco Bay water if sediment mercury concentrations were at pre-anthropogenic levels. The data next to each location specify the highest total recoverable mercury concentrations (μg mercury per liter of water) predicted for the percentage of time specified in the column headers; i.e., mercury at Mallard Island near the surface would be less than 0.002 - 0.004 μg/L 50% of the time, and less than 0.004 - 0.008 μg/L 95% of the time for the period measured if sediment mercury concentrations were between 0.05 and 0.10 μg/g. Italicized numbers indicate exceedance of Basin Plan objectives (0.025 μg/L).

Section 3.1 Key Points:

- The Basin Plan objective applies for total recoverable mercury (0.025 μg/L) applies to waters north of the Dumbarton Bridge.
- The Federally Establish California Toxics Rule (CTR) criterion for total recoverable mercury (0.051 μg/L) will apply to waters South of the Dumbarton Bridge.
- Total recoverable objectives are not the best way to protect beneficial uses, because they don't directly address methylmercury, which is the form that bioaccumulates
- The current Basin Plan objective (0.025 μg/L) is still an environmentally relevant metric of mercury contamination, even though it is a total recoverable objective.
- If we had pre-anthropogenic mercury concentrations in sediments (0.05-0.10 μg/g), we would rarely exceed the Basin Plan objective for total recoverable mercury (0.025 μg/L), because of the direct link between sediment and total recoverable concentrations.
- Contemporary mercury concentrations in San Francisco Bay suspended sediments (0.26 - 0.46) are higher than pre-anthropogenic levels.
- A sediment target for mercury will move waters of the San Francisco Bay estuary towards attainment of Basin Plan objectives.

3.2 Narrative Objectives

The 1995 Basin Plan contains a narrative objective for bioaccumulative substances:

> Many pollutants can accumulate on particles, in sediment, or bioaccumulate in fish and other aquatic organisms. Controllable water quality factors shall not cause a detrimental increase in concentrations of toxic substances found in bottom sediments or aquatic life. Effects on aquatic organisms, wildlife, and human health will be considered.

That narrative objective addresses three factors relevant to target development:

i) mercury concentrations in sediments and suspended particles;
ii) mercury concentrations in aquatic life, including fish; and
iii) effects on the people and animals that eat fish.

The first factor, mercury concentrations in sediments and suspended particles, is directly related to exceedance of Basin Plan objectives (*see above*). The second and third factors are related to mercury methylation and bioaccumulation in aquatic ecosystems. Targets related to the narrative objective are discussed in the following sections.

Section 3.2 Key Points:

- The Basin Plan narrative objective supports a target for mercury concentration in sediments.
- The objective also supports a target that addresses methylation and bioaccumulation by fish and wildlife.

3.3 Mercury concentrations in sediments

Basin Plan water quality objectives are routinely exceeded because of contaminated sediments in the Bay (*see above*). A sediment target should be developed to control the largest ongoing watershed sources that contribute mercury-contaminated sediments. This requires some understanding of the superimposed processes controlling mercury concentrations in sediments:

i) inputs from the watershed;
ii) particle size sorting; and
iii) inputs from locally elevated sources.

3.3.a Mercury inputs from watershed sediments

San Francisco Bay sediments come predominantly (76-86 %) from the Sacramento – San Joaquin River Delta[31 32]. We therefore should expect San Francisco Bay sediments to reflect the typical concentrations of mercury in sediments of the Sacramento and San Joaquin River watersheds that drain into San Francisco Bay. A recent survey of trace element concentrations in benchmark soils, removed from contaminated hotspots, helps evaluate the expected concentrations of mercury in sediments from those two watersheds. [33]. For twenty-two soil samples, the median mercury concentration is 0.22 µg/g (Table 9). That observation is consistent with the RMP's independent assessment showing that the typical concentration of mercury in suspended particles entering the estuary is ≈0.2 µg/g (Figure 16, Figure 17). Mercury concentrations in sediments entering the estuary match mercury concentrations in the upland Central Valley watershed.

However, those sediment concentrations (0.2 µg/g) are two to four-fold higher than pre-anthropogenic concentrations (0.05 – 0.1 µg/g [29]). The benchmark soils in the Kearny Foundation report were deliberately taken from sites removed from contaminated hot spots, so direct mercury inputs from mining operations is not a likely explanation. The elevated concentration of mercury in contemporary watershed sediments may be related to increased global mercury atmospheric releases, which are two to three times higher than natural (primarily volcanic) emissions. There may be other explanations, but in any case, it would be unreasonable to expect concentrations of mercury in bulk sediments to be lower than contemporary concentrations typical of the upland watershed.

This is a starting point for establishing a sediment target, but it needs to be refined. Mercury concentrations in suspended sediments increase steadily from the Sacramento River to a maximum at the Golden Gate (Figure 17). This is most likely a result of particle size sorting, as discussed in the Problem Statement (section 2.2.d). In contrast, the concentration gradient in the South Bay is caused by inputs of mercury-laden sediments. This is clearly illustrated by examining the relationship between particle size and merury concentrations, as discussed in the nest section.

Soil Number	County of Origin	[Hg] µg/g
2	Glenn	0.10
3	Tehama	0.70
4	El Dorado	0.27
5	El Dorado	0.61
6	Tehama	0.10
9	San Joaquin	0.27
10	Merced	0.49
11	San Joaquin	0.10
13	Fresno	0.10
14	El Dorado	0.22
15	El Dorado	0.21
17	Solano	0.10
21	Fresno	0.25
24	Modoc	0.10
26	Lake	0.10
29	Glenn	0.75
30	Lake	0.22
34	Merced	0.66
38	San Joaquin	0.10
41	Merced	0.10
46	Solano	0.34
49	San Joaquin	0.25
Median		0.22
Max		0.75
Min		0.10

Table 9: Concentrations (µg/g) of mercury in twenty-six benchmark soils from the California watershed draining into San Francisco Bay. Data from the Kearney Foundation Special Report on Background Concentrations of Trace and Major Elements in California Soils[33].

3.3.b Particle size sorting

One of the primary controls on mercury concentrations in sediments is grain size. Mercury concentrations tend to increase with increasing amounts of fine material. This is generally true for most particle-bound pollutants: the amount of surface area available to trap pollutants for a given mass of sediment increases with increasing amounts of fine material.

In general, there is a linear relationship between mercury concentrations and percentage of fine sediments in San Francisco Bay (Figure 22). There are significant outliers from this regression, most notably in the lower South Bay. During the winter of 1997, sediments with mercury concentrations of ~1 µg/g were found at the mouth of the Guadalupe River, well in excess of concentrations predicted from grain-size effects. Inputs from the Guadalupe River affect sediments throughout Lower South Bay.

Figure 22 helps understand how to derive a numeric target for mercury concentrations in sediments that can be used in a box model to calculate assimilative capacities. Qualitatively, what we are saying is that we expect baywide sediments to reflect the source material from the upland watershed. Mercury concentrations in that sediment source vary according to the percentage of fine sediments present. The heavy black line in Figure 22 shows the expected relationship between mercury concentrations and percent fines. That line is derived from a regression on the lower 75'th percentile of the RMP sediment data [1], to remove the influence of contaminated sediments. It is consistent with the mercury – grain size relationship observed in bedded sediments taken exclusively from the Sacramento River mouth. Sediments that are significantly above this line are over the target.

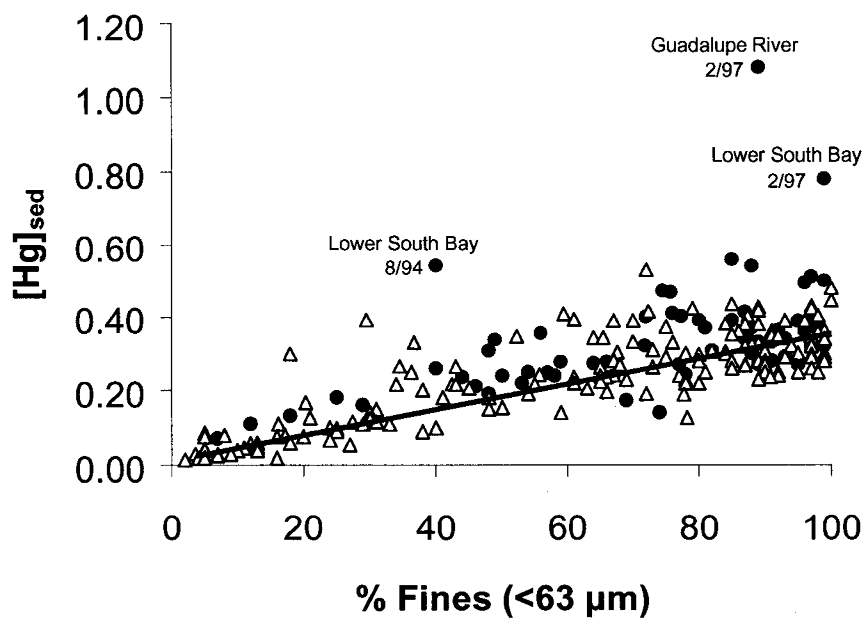


Figure 22: Mercury concentrations (µg/g) in San Francisco Bay sediments vs. percent fines (<63 µm). Graph of 225 data points from the RMP, 1993-1997 [1]. Open triangles depict northern reach sediments, closed circles depict South Bay sediments. The heavy black line shows the best fit linear regression on the lower 75'th percentile of the data.

Quantitatively, we have to select a numeric value that can be used to calculate assimilative capacities and loads. The target value should be the concentration of mercury in sediments, normalized to the percentage of fine material (<63 μm). This is calculated as:

Equation 2

$$[Hg]_{norm} = [Hg]_{sed} / (F_{63})$$

Where:

$[Hg]_{norm}$ = Sediment concentration normalized to percent fines (μg/g)
$[Hg]_{sed}$ = Bulk sediment concentration (μg/g)
F_{63} = Percent fines (<63 μm), expressed as a fraction ($0 \leq F_{63} \leq 1$)

The median value $[Hg]_{norm}$ from ten sediment samples collected from the mouth of the Sacramento River in the RMP[1], 1993-1997, is 0.40 μg/g. This value will be used in the linkage analysis to calculate assimilative capacities and derive loads. Ambient waterbodies and conveyances with medians above this value are considered to be over the target, and contributing to the elevation of mercury concentrations in San Francisco Bay sediments beyond levels expected from normal sediment transport processes.

3.3.c Evaluation of the sediment target

Figure 23 shows where segments of the Bay exceed the 0.4 ug/g target value. Three areas of the Bay have normalized sediment concentrations that are generally higher than source sediments from the Sacrament River Basin: Lower South Bay, San Pablo Bay, and the San Joaquin River mouth. The first one is clearly related to mining inputs. Lower South Bay is impacted by ongoing inputs from the Guadalupe River, which drains the New Almaden Mining district.

San Pablo Bay received massive inputs of mercury-laden sediment during and after the hydraulic mining era. Exceedance of the target in this segment may result from remobilization of those historic deposits. It may also be due to inputs from past mercury mining operations in the Petaluma and Napa river watersheds (Figure 5). This needs to be resolved to determine the most effective control measures.

The cause of target exeedance at the San Joaquin River mouth also needs to be investigated. It may be due to a local legacy mining source. The Mt. Diablo mercury mine has increased mercury concentrations in sediments of Marsh Creek to as much as 1 ppm in its lower reaches[34], and Marsh Creek drains into the San Joaquin River. However, unlike the Guadalupe River system, the San Joaquin drains a much larger watershed. Additional information needs to be gathered to determine whether exceedance of the target value in the San Joaquin River mouth is caused by local or regional processes, and whether the proposed sediment target is appropriate to the San Joaquin River watershed. The skewed distribution about the median in the San Joaquin River (Figure 23) tentatively suggests that exceedance of the target is caused by sporadic inputs from localized sources rather than general watershed loading.

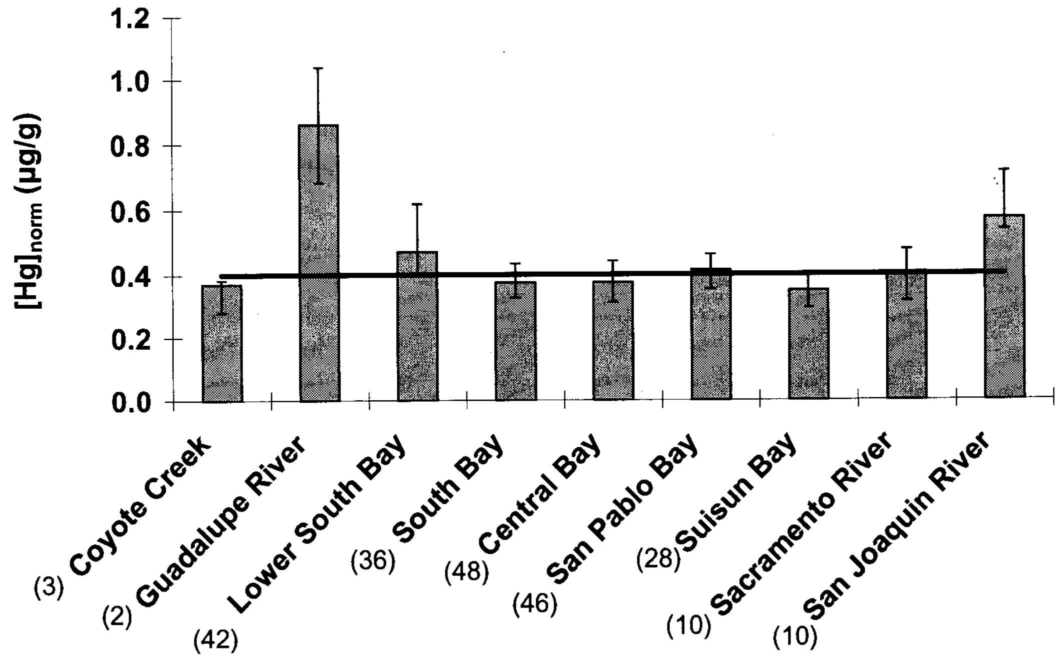


Figure 23: Evaluation of the sediment target in San Francisco Bay waterbodies and conveyances. The solid grey bars indicate the median values for $[Hg]_{norm}$; the error bars indicate the 75'th and 25'th percentiles; the numbers in parentheses indicate the number of measurements in each waterbody of conveyance. The solid black horizontal line shows the TMDL target ($[Hg]_{norm}$ = 0.40 µg/g).

The sediment target of 0.40 µg/g in sediments <63 µm addresses the largest ongoing external sources of mercury to the San Francisco Bay estuary. However, this target should also be linked to protection of beneficial uses. This requires another target that addresses mercury bioaccumulation. The bioaccumulative form of mercury is methylmercury, so a target for dissolved methylmercury in water is also needed. Much of the information needed to establish a methylmercury target for San Francisco Bay is preliminary or missing. However, after summarizing the guidelines for mercury in fish consumed by humans and targets protective of endangered wildlife, a reasonable estimate can be proposed for a methylmercury target. This target can be revised in the second phase of the TMDL as new information becomes available.

Section 3.3 Key Points:

- A mercury sediment target is needed to control the largest ongoing sources
- Mercury concentrations in sediments increase with increasing amounts of fine-grained material.
- To account for the particle-size effect, mercury concentrations can be normalized to the percentage of fine material (<63 μm).
- The proposed sediment target is 0.4 μg/g, which is the median of mercury concentrations of sediments (normalized to percentage of fines) from the mouth of the Sacramento River.
- Sediments from three areas of the Bay have normalized concentrations above the proposed target (0.4 μg/g): Lower South Bay, San Pablo Bay, and the San Joaquin River.
- The New Almaden Mine and its downstream watershed cause exceedance of the target in Lower South Bay
- The source for San Pablo Bay may be either resuspension of historic deposits or ongoing inputs from the Petaluma mining district. This needs to be resolved.
- The source to the San Joaquin River may be either the inoperative mercury mine in the Marsh Creek drainage or a more regional processes in the San Jaoquin River Basin. This needs to be resolved.

3.4 Fish Consumption Guidelines

Guidelines for mercury concentrations in fish that are protective of human health are summarized in Table 10. The lower candidate targets (0.14 and 0.23 mg/kg) are screening values. Exceedance of screening values does not necessarily mean that beneficial uses are impaired, but that additional monitoring and assessment is warranted to determine if impairment exists. The higher candidate targets (1 mg/kg) are action levels. Fish consumption advisories are posted when commercial and sport fish exceed these concentrations.

Establishment of fish tissue concentration targets for the San Francisco Bay region is essential to development of a TMDL that protects human health. The Sacramento River Watershed Program has conducted a thorough review of fish consumption guidelines as part of its target development [35]. We have participated in that effort, and recommend using the cited report as a starting point for developing fish tissue targets for adoption in the second phase of the mercury TMDL (Section 3.6)

There is an ongoing, debate regarding acceptable daily intakes of mercury by humans. The National Academy of Sciences has convened a panel of experts to resolve this issue. We have contacted the National Academy of Sciences directly, but they will not release the preliminary results from the report until it is finalized and reviewed. After that, we need to work with OEHHA and the stakeholders to relate that daily dosage to fish tissue concentrations, using fish consumption rates and habits of the San Francisco Bay Area residents. A fish tissue target needs to be standardized to the age and size of the target species, because of the increase in mercury concentrations with increasing fish age (Figure 9).

Because of these outstanding issues, establishment of a fish tissue target should take place in the second phase of the TMDL. For the first phase, the FDA action level (1 mg/kg) will be combined with the best available information on methylmercury bioaccumulation to derive a dissolved methylmercury target. That target is discussed in Section 3.6 below.

Fish Tissue Guidelines (mg/kg)	Comments	Reference
0.33	corresponds to U.S. EPA RfD assuming a 60 kg individual and 18 g/day consumption[a]	MRC Vol. VII, 1997
1	corresponds to ATSDR minimum risk level assuming a 60 kg individual and 18 g/day consumption[a]	ATSDR (www.atsdr.cdc/gov/press/ ma990419.html); ATSDR (1999)
0.6	U.S. EPA screening value	U.S. EPA (1995)
0.23	Screening value calculated by San Francisco Estuary Institute (SFEI)[b]	SFEI (1999a)
0.14	Screening value calculated by SFRWQCB	SFRWQCB (1995)
1	FDA action level	FDA (vm.cfsan.fda.gov/~dms/)

(a) 60 kg is the default body weight for an adult female used by U.S. EPA in calculation of the RfD (U.S. EPA, 1997). 18 g/day (rounded from 17.8) is the default fish intake rate proposed by U.S. EPA for protection of the general population and sport anglers (U.S.EPA, 1998).

(b) Screening value calculated using U.S. EPA guidance, 30 g/d consumption rate, and an updated reference dose.

Table 10: Summary of fish consumption guidelines, from the Sacramento River Watershed Program report on Identification and Assessment of Candidate Targets for the Mercury Strategic Planning Effort [35].

Section 3.4 Key Points:

- The best available target for fish tissue is the 1 µg/g FDA action level.
- In the first phase of the TMDL, we need to develop better information to revise the fish tissue target.
- One outstanding issue is the level of acceptable daily intake of mercury by humans.
- Another question is a regionally specific bioaccumulation factor for methylmercury.

3.5 Wildlife Protection Considerations in Numeric Target Selection

Two parallel approaches to protecting wildlife were considered in the Sacramento River Watershed Project numeric targets workgroup. One approach is to set a target for methylmercury concentration in water (Table 11). This is reasonable, because methylmercury is the form that bioaccumulates in the food chain. Another approach is to set targets for mercury concentrations in higher trophic level fish (Table 12). This is more directly related to the mercury dosage delivered to wildlife species that obtain their food from the Bay. As with fish tissue targets for protection of human health, fish tissue targets protective of wildlife must consider consumption rates, foraging habits, and be standardized to fish species and age.

Another approach to protecting wildlife is to develop a target for mercury concentrations in avian eggs. Embyros are the most sensitive life-stage, so an avian egg target is a valuable tool for protecting rare and endangered avian species that nest and feed in San Francisco Bay. The effects of methylmercury on mallard ducks have been documented in studies spanning several generations[36-39].

Species upon which target is based	Methyl-Mercury Water Target (ng/L)
Mink	0.057
Otter	0.042
Kingfisher	0.033
Osprey	0.082
Eagle	0.100
lowest average based on all wildlife species studied in Hg Report to Congress[b]	0.050

a) U.S. EPA converted criteria values using an estimate of 0.078 methyl mercury as a proportion of total (U.S. EPA, 1997).
b) Mean wildlife criteria values were determined for all mammalian species (0.05 ng/L) and all avian species (0.074 ng/L). The lowest of these two means, 0.05 ng/L, was selected by U.S. EPA as the wildlife criteria value for methyl mercury (U.S. EPA, 1997).

Table 11: Summary of candidate water column methylmercury targets for protection of wildlife, from the Sacramento River Watershed Program report on Identification and Assessment of Candidate Targets for the Mercury Strategic Planning Effort [35]. All of the target values originally come from the Mercury Study Report to Congress, Volume VI.

Species upon which target is based	Fish Tissue Target (mg/kg)	Comments	Reference
Mink	0.091 / NA	Hg conc. corresponding to water conc. In Table 11 (trophic 3 / trophic 4)[a]	Mercury Report to Congress (MRC) Vol. VI, 1997
Mink	0.077 / NA	Hg conc. corresponding to water conc. in Table 11 (trophic 3 / trophic 4)[a]	Great Lakes Water Quality Criteria (as presented in Report to Congress)
Otter	0.067 / 0.285	Hg conc. corresponding to water conc. in Table 11 (trophic 3 / trophic 4)[a]	MRC Vol. VI, 1997
Otter	0.05 / 0.27	Hg conc. corresponding to water conc. in Table 11 (trophic 3 / trophic 4)[a]	Great Lakes Water Quality Criteria (as presented in MRC)
Kingfisher	0.053 / NA	Hg conc. corresponding to water conc. in Table 11 (trophic 3 / trophic 4)[a]	MRC Vol. VI, 1997
Kingfisher	0.028 / NA	Hg conc. corresponding to water conc. in Table 11 (trophic 3 / trophic 4)[a]	Great Lakes Water Quality Criteria (as presented in MRC)
Osprey	0.13 / NA	Hg conc. corresponding to water conc. in Table 11 (trophic 3 / trophic 4)[a]	MRC Vol. VI, 1997
Eagle	0.16 / 0.68	Hg conc. corresponding to water conc. in Table 11 (trophic 3 / trophic 4)[a]	MRC Vol. VI, 1997
Eagle	0.051 / 0.27	Hg conc. corresponding to water conc. in Table 11 (trophic 3 / trophic 4)[a]	Great Lakes Water Quality Criteria (as presented in MRC)
lowest average based on all wildlife species studied in MRC	0.08 / 0.34	Hg conc. corresponding to water conc. in Table 11 (trophic 3 / trophic 4)[a]	MRC Vol. VI, 1997
Merganser	0.1 – 0.3	see footnote (b)	Draft Regional Toxic Hot Spot Cleanup Plan, CVRWQCB 1998.

(a) Based on assumed bioaccumulation factors for trophic levels 3 and 4.
(b) Safe level of 0.1 determined from Heinz, 1979 mallard study (which was also used for GLWQI and Mercury Report to Congress). US Fish and Wildlife Service used the DOE toxicological benchmark uncertainty factor of 3 for LOAEL to NOAEL conversion.

Table 12: Summary of candidate fish tissue targets for protection of wildlife, from the Sacramento River Watershed Program report on Identification and Assessment of Candidate Targets for the Mercury Strategic Planning Effort [35].

A current study, conducted by U.S. FWS and funded by a CALFED grant [40] is developing dose-response curves using methods similar to the mallard duck studies to help establish targets for avian species relevant to San Francisco Bay. The Regional Board has supplemented the U.S. FWS study with state TMDL funds to extend the field component into San Francisco Bay. We will use that information to establish avian egg targets for the second phase.

Although more information is needed to establish fish tissue and avian targets for mercury, we know enough now about mercury bioaccumulation to establish a conservatively low target for dissolved methylmecury in water that links proposed control measures to protection of both human health and wildlife. Our best estimate of that target, and the rationale behind it, is discussed in the next section..

Key Points for Section 3.5

- The most environmentally conservative target for protection of wildlife should be set for methylmercury in water.
- That target should reflect the endpoint of mercury levels in
  1) fish tissue
  2) avian eggs
  3) human predators of wildlife
- The Regional Board is collaborating with U.S. FWS and CALFED to develop an avian egg target in phase two of the TMDL.

3.6 Dissolved Methylmercury Target in Water

A target for dissolved methylmercury in water can be derived using the estimates of the bioaccumulation for methylmercury and existing federal guidelines for mercury in fish. A target derived this way is also consistent with the maximum methylmercury concentrations thought to be protective of wildlife. Thus, with one single target, protection of many beneficial uses (e.g. COMM, RARE, WILD) can be achieved.

The FDA action level for mercury concentration in fish is 1 mg/kg. The best available bioaccumulation factor for higher trophic level fish is 6.86×10^6, which we will conservatively round up to 10^7 (ten million). This bioaccumulation factor, derived from a recent U.S. EPA scientific review[41], is for mercury bioaccumulation in freshwater lakes. That same study indicated a need to develop a bioaccumulation factor for methylmercury in marine and estuarine ecosystems. While this is clearly a research need for the San Francisco Bay estuary, the bioaccumulation factor of 10^7 is the best estimate we have, and so will be used in the first phase of the TMDL. An improved assessment of the site-specific methylmercury bioaccumulation factor for San Francisco Bay will be developed for implementation in the second phase of the TMDL.

The bioaccumulation factor (BAF) quantifies the ratio of methylmercury concentrations in fish ($[MeHg]_{fish}$) to dissolved methylmercury concentrations in ambient water ($[MeHg]_{water}$), accounting for both direct exposure and food chain accumulation. Mathematically, it is defined as:

Equation 3

$$\text{BAF (L/kg)} = \frac{[\text{MeHg}]_{fish}\ (\text{mg/kg})}{[\text{MeHg}]_{water}\ (\text{ng/L})} \times \frac{1{,}000{,}000\ \text{ng}}{\text{mg}}$$

Equation 3 can be rearranged to calculate a dissolved methylmercury target from a fish tissue objective and a bioaccumulation factor:

Equation 4

$$[\text{MeHg}]_{water}\ (\text{ng/L}) = \frac{[\text{MeHg}]_{fish}\ (\text{mg/kg})}{\text{BAF (L/kg)}} \times \frac{1{,}000{,}000\ \text{ng}}{\text{mg}}$$

Substituting in the FDA action level of 1 mg/kg for $[MeHg]_{fish}$ and a bioaccumulation factor of 10^7 into Equation 4 yields a $[MeHg]_{water}$ target of 0.1 ng/L, or 0.0001 µg/L. This is the concentration limit for methylmercury in water that will keep mercury concentrations in fish at or below 1 mg/kg.

The $[MeHg]_{water}$ target of 0.1 ng/L derived from the FDA action level is comparable to $[MeHg]_{water}$ levels considered protective of wildlife (Table 11). The lowest average for all wildlife species studied in the Mercury Study Report to Congress was 0.05 ng/L. Selection of the lower $[MeHg]_{water}$ target (0.05 ng/L) should protect both wildlife and human consumers of fish from San Francisco Bay. As discussed in the Problem Statement, many wildlife species get 100% of their protein from the Bay, so targets protective of wildlife should also be protective of human subsistence fishers.

The dissolved methylmercury target can be compared to ambient conditions using a preliminary assessment of dissolved methylmercury concentrations in the San Francisco Bay estuary (Table 13). This study was conducted as part of the RMP sampling efforts in 1999, using supplemental funds from the Regional Board's 1999 laboratory contract budget.

Overall, the Bay is below the dissolved methylmercury target. Median values for the entire Bay are 0.030 ng/L in January, 1999 and 0.021 ng/L in April, 1999. However, some regions within the Bay are above the target. The highest concentration of dissolved methylmercury observed in either sampling period was 0.109 ng/L, in Guadalupe slough.

The linkage is unequivocal between inputs from inoperative mines of the Almaden District and impairment of beneficial uses in the downstream watershed. The sediment target shows an ongoing mercury source from that watershed (Figure 22). Mercury in sediments within that watershed is converted to methylmercury, leading to subtantially enriched methylmercury in sediments. Dissolved methylmercury concentrations in Lower South Bay, downstream of the Guadalupe River are high enough to lead to fish tissue concentrations in excess of the 1 ppm FDA action level.

	January, 1999		April, 1999	
Location	Diss. Hg µg/L	Diss. MeHg ng/L	Diss. Hg µg/L	Diss. MeHg ng/L
Standish Dam	0.0029	***0.074***	<dl	0.034
San Jose	0.0008	0.004	0.0007	
Guadalupe River	0.0350		0.0001	
Guadalupe Slough	0.0032		0.0004	***0.109***
Lower South Bay	0.0005		0.0002	0.013
South Bay	0.0002	<dl	0.0008	
Dumbarton Bridge	0.0009		0.0009	
Redwood Creek	0.0008		0.0004	0.037
San Bruno	0.0006	***0.086***	0.0003	0.013
Oyster Point	0.0005		0.0001	0.009
Alamaeda	0.0005		0.0001	<dl
Yerba Buena Island	0.0003		0.0001	0.021
Golden Gate	0.0003	0.012	0.0002	<dl
Richardson Bay	0.0002		0.0001	***0.055***
Point Isabel	0.0003		0.0001	0.020
Red Rock	0.0003		0.0001	0.019
Petaluma River	0.0319	0.030	0.0005	0.003
San Pablo Bay	0.0008	0.009	0.0003	0.033
Pinole Point	0.0011		0.0003	
Davis Point	0.0020		0.0003	
Napa River	0.0041		0.0008	
Pancheco CRiver	0.0030		0.0004	
Grizzly Bay	0.0015	0.017	0.0005	0.013
Honker Bay	0.0027		0.0001	0.022
Sacramento River	0.0016	***0.052***	0.0004	0.028
San Joaquin River	0.0012	***0.087***	0.0012	0.013

Table 13: Preliminary assessment of concentrations of dissolved mercury and dissolved methylmercury in the San Francisco Bay Estuary, in January and April, 1999. Italicized numbers indicate exceedance of the proposed dissolved methylmercury target (0.050 ng/L). Data provided courtesy of The Chesapeake Biological Laboratories and the San Francisco Estuary Institute.

The connection between sources and exceedance of the proposed dissolved methylmercury target in other Bay segments is less clear. The San Joaquin River station was over the target in January, 1999, and the sediments in this region also exceed the sediment target. But it is unknown whether this exceedance is caused by local or regional sources. Methylmercury in Richardson Bay, near the Golden Gate, exceeded the target in April, 1999, while surrounding stations were below the target. Methylmercury in the Coyote Creek watershed station at Standish Dam exceeded the target, but after dilution with wastewater from the City of San Jose, was below the target. Much further to the north, Bay waters off the San Bruno Shoals once again exceeded the target. The latter two examples underscore the point that within-Bay processes may be as important as external sources in controlling methylmercury concentrations.

Section 3.6 Key Points:

- A dissolved methylmercury target in water of 0.1 ng/L protects of human health, based on the FDA action level of 1 mg/kg in fish tissue and a bioaccumulation factor of 10 million.
- A more protective dissolved methylmercury target in water of 0.05 ng/L protects of wildlife based on the lowest average for all species from the Mercury Report to Congress.
- We propose a methylmercury in water target of 0.05 ng/L based on the lower of the above two numbers to protect both humans and wildlife.
- This target is based on research derived primarily from the Great Lakes, which has very different sources, geochemical processes, ecosystems than San Francisco Bay
- The dissolved methylmercury target should be reviewed and refined as we develop more information specific to San Francisco Bay
- As a whole, the bay is below the target value of 0.05 ng/L.
- The spatial distributions that we have observed confirm that within-bay methylmercury production is an extremely important process.
- The highest methylmercury concentration observed (0.11 ng/L) is in Guadalupe Slough, where the sediment target also indicates ongoing inputs of total mercury.

3.7 Selected targets for adoption in the first phase of the TMDL

To summarize, two targets have been selected for adoption in the first phase of the TMDL. Together, the two targets address control of the largest sources of mercury to San Francisco Bay and protection of its beneficial uses, including sport fishing (COMM), protection of rare and endangered wildlife (RARE), and wildlife habitat (WILD).

The first is a sediment target of 0.40 μg mercury per gram of sediment, normalized to the percentage of fine material (<63 μm) present (i.e. $[Hg]_{norm}$), as defined in Equation 2. This target should be implemented by evaluating the bulk sediment mercury concentrations and percentage of fine sediments in a waterbody or conveyance (e.g. tributary or stormwater outfall). Either bedded sediments or suspended sediments may be used to evaluate the target. At least five data points should be used to evaluate the target, and twelve or more is desirable. The normalized sediment concentration target is intended to evaluate impairment in waterbodies, perform mass balance calculations, and identify conveyances that elevate in-Bay sediment concentrations of mercury above the range expected for normal sediment transport processes in our watershed.

If the median value of $[Hg]_{norm}$ in a segment of the Bay is over the target, that may indicate inputs of contaminated sediment, and will require additional monitoring to identify potential sources. If seventy-five percent of the observations from a segment of the Bay are over the target, that is defined as a significant exceedance, and will require calculation of assimilative capacity and allocation of loads within that segment. If the median of a conveyance is over the target, that will require a source investigation to determine the cause of the exceedance.

The second is a dissolved methylmercury ($[MeHg]_{diss}$) target of 0.05 ng methylmercury per liter of water. Dissolved is operationally defined as the fraction of water passing through a 0.45 μm filter at the time of sample collection. This target should be implemented by evaluating the median of methylmercury concentrations in a waterbody. A measure of central tendency is used to characterize the typical, long-term conditions experienced by organisms in a waterbody. This target is not intended to apply to conveyances or inputs (e.g., wastewater, tributaries, and stormwater outfalls), because *in-bay* methylmercury production likely outweighs direct conveyances of methylmercury (*see below*, Source Assessment section and Linkage Analysis section). It should be noted that large inputs of total mercury especially bioavailable mercury likely will affect the overall in-Bay methylation rate. The dissolved methylmercury target is intended to evaluate impairment in waterbodies and perform mass balance calculations.

Both of these are interim targets, for adoption in the first phase of the TMDL. The sediment target may be adjusted upward or downward in the second phase of the TMDL, as new information becomes available on watershed sources of mercury. The methylmercury target may also be adjusted upward or downward, after establishing a fish tissue target and reviewing or revising the bioaccumulation factor. Interim targets for the first phase of the TMDL allow for an adaptive management approach that takes action immediately on the most obvious causes of impairment and creates flexibility to take additional actions as we learn more about mercury cycling in San Francisco Bay.

Section 3.7 Key Points:

- A sediment target $[Hg]_{norm}$ of 0.4 µg/g, and a dissolved methylmercury in water target of 0.05 ng/L, is proposed for the first phase of the TMDL.
- The proposed sediment target should be applied as a median concentration of bedded sediments in a waterbody, and of suspended sediments transported by a conveyance into the Bay. Median concentrations greater than $[Hg]_{norm}$ = 0.4 µg/g exceed the target.
- The proposed methylmercury in water target should be applied as a median concentration to assess the long-term conditions experienced by aquatic organisms in the Bay. It should not be applied to conveyances to the Bay (such as tributaries, wastewater discharges, and storm water outfalls), because it is within-bay production of methylmercury that drives bioaccumulation.
- Both proposed targets are interim and may be adjusted in phase two of the TMDL if new information is available.
- The sediment target is exceeded by the greatest margin, and is directly linked to exceedance of the numeric criteria and objectives
- The first phase TMDL will be based on attainment of the sediment target.
- The dissolved methylmercury target will be used to identify impaired segments, and will be applied in the second phase to review and refine the TMDL once we have a better understanding of mercury methylation within the bay.

3.8 Proposed numeric targets for adoption in the second phase of the TMDL

The two targets proposed above are both measurements of sediment and water quality related to impairment of beneficial uses. The second phase of the TMDL should establish targets that more directly assess beneficial uses. A fish tissue target is needed to protect human and wildlife consumers, and an avian egg target is needed to protect the most sensitive resident wildlife. Once those targets are established, the sediment and water quality targets proposed in phase one should be reviewed and revised, and additional targets should be established as appropriate. This section briefly describes the target development work needed for the second phase of the TMDL.

3.8.a Fish tissue targets

Three types of additional information are being gathered for development of a fish tissue target: regional monitoring data, human health consumption guidelines, and fish consumption patterns in the San Francisco Bay Area. The RMP is continuing its surveillance of mercury levels in fish tissue. The NAS panel of experts is expected to deliver a report in the summer of 2000 on dietary mercury exposure limits for humans. In addition, OEHHA will be reviewing and revising its fish consumption advisory for San Francisco Bay. Some preliminary studies are available on types and amounts of fish being eaten by Bay Area citizens [42-45].

We need a stakeholder workgroup to assemble all available information, identify any other information needs, and determine a fish tissue target. That workgroup should include concerned citizens, OEHHA, USWFS staff, and California Department of Fish and Game staff. The fish tissue target should be focused on sport fish and fish caught for food, and should account for age and size variation, as well as any other relevant factors.

3.8.b Avian egg targets

San Francisco Bay is home to numerous species of birds, both resident and migratory, that feed on the fish and benthic fauna within the estuary. The Bay is an important stopover on the Pacific Flyway, and is a nesting ground for endangered wildlife, including the California Clapper Rail. The life stage of an organism most sensitive to mercury toxicity is the embryo. Development of an avian egg target will help protect birds that nest in the Bay.

The Regional Board has initiated a contract with U.S. FWS to assess concentrations of mercury in avian eggs in the Bay Area. CALFED has funded a study of mercury concentrations in avian eggs from the Delta, and of the relationship between mercury concentrations in eggs and reproductive impairment. All of this information will be combined and evaluated to help develop a target for mercury concentrations in avian eggs. This target development should be done in partnership with staff of the Central Valley Regional Board, who are also developing an avian egg target, as well as U.S. FWS and CADFG staff.

3.8.c Related sediment and water quality targets

After setting fish tissue targets and avian egg targets, the targets established for total mercury in sediments and dissolved methylmercury in water should be reviewed to address the following issues:

- Are the targets set low enough to protect the relevant tissue compartments?
- Are they set unnecessarily low?
- Are additional targets needed?

Additional targets that should be considered are methylmercury in sediments, and methylmercury to total mercury ratios in sediment and water. These parameters can be useful indicators of the relative methylation efficiency of a waterbody or wetland [30]. Identifying areas of enhanced methylation, particularly in the margins and shallow areas of the estuary, will be important for making decisions about wetland creation, management, and the disposal of dredge material.

Finally, we should develop a target for bioavailable mercury in sediment and water. Bioavailable mercury means the fraction of total mercury in either sediment or water than can be converted to methylmercury. There have been some recent studies showing how to quantify mercury bioavailability [46-48]. The CALFED study will also assess bioavailability of mercury from all sources within the Central Valley Region.

A target for bioavailable mercury is essential to coordinate TMDL efforts between the San Francisco Bay and Central Valley Regions. The residence time of methylmercury in a waterbody is days at best; it is rapidly lost due to photo-ablation or microbial demethylation. Therefore, production of methylmercury within the Bay is a much more likely cause of impairment than direct methylmercury inputs from the Central Valley. To effectively control sources in the Central Valley that impair beneficial uses in San Francisco Bay, we have to understand which of those mercury sources are actually converted to methylmercury in our region. The CALFED study expects to produce preliminary assessments for bioavailable mercury by 2004. With that information, we can set targets and establish load allocations for the Central Valley in the second phase of the TMDL.

Section 3.8 Key Points:

- Phase two of the TMDL should establish targets that are more directly linked to beneficial uses; these include a fish tissue target, an avian egg target, any necessary revisions to the targets for sediment and methylmercury in water, and the need for other targets.
- Establishment of a fish tissue target should consider information being generated in the following areas: fish tissue concentrations measured by the RMP, fish consumption advisories and risk assessments posted by OEHHA, dietary exposure limits reviewed by the NAS, and fish consumption patterns in the San Francisco Bay Area by various agencies and groups.
- Establishment of an avian egg target should consider information being generated by the U.S. FWS under CALFED to relate the mercury concentrations in eggs to reproductive impairment.
- Other targets for consideration in phase two may include methylmercury in sediments and bioavailable mercury in sources to the Bay.
- Methylmercury in sediment can be an indicator of methylation efficiency so a target would be a useful tool for managing the Bay and adjoining wetlands.
- Bioavailable mercury in sources shows which are contributing mercury into the Bay that ultimately ends up in fish.
- A target for bioavailable mercury will direct the most effective source control strategies to minimize methylmercury. This is particularly importance for mercury input from Central Valley sources.

4. Source Assessment

4.1 Assessing mercury sources in a complex estuary

4.1.a Approach

This section summarizes sources of *total* mercury to San Francisco Bay. Inputs of total mercury are linked to beneficial use impairment (*e.g.*, bioaccumulation in fish) through the process of methylation. Mercury methylation is discussed in the linkage analysis section. Our approach to mercury management is to first identify the largest ongoing sources of mercury, and then ask whether those inputs are also associated with exceedance of the dissolved methylmercury target. By linking sources to impairment of beneficial uses, we can establish a rational basis for requiring load reductions.

The Bay has to be divided into segments, because of the complex flow and circulation patterns found within the estuary. The next section (4.1.b) explains the segmentation of the estuary and the relevant properties and processes in each segment. Many of the load calculations are based on sediment concentrations and sediment transport. Section 4.1.c explains the basis for this, presents an overview of the sediment budget in San Francisco Bay, and states the assumptions and calculations used to derive mercury mass from sediment mass.

Section 4.1.a Key Points

- This section summarizes loadings of total mercury
- A complete load analysis has to divide the Bay into segments
- Many mercury loads can be estimated from sediment transport processes

4.1.b Segmentation of the estuary

The calculations needed for a source assessment, linkage analysis, and determination of assimilative capacity require segmentation of the Bay into distinct hydrographic regions, because it is a complex, heterogeneous waterbody. As discussed in the Problem Statement (Section 2), the Bay has two distinct hydrographic environments: the well-flushed northern reach and the lagoon-like southern reach. Within both of these subregions there are smaller segments that have to be treated separately in a TMDL analysis. Each segment has a unique set of processes related to mercury fate and transport.

The Basin Plan divides the Bay into six segments (Figure 24): Suisun Bay, Carquinez Strait, San Pablo Bay, Central Bay, Lower Bay, and South Bay. These terms have important legal meaning in the 303(d) listing process. The entire bay may be listed as impaired, or only certain segments may be listed. It is important to keep these segments in mind, because of their legal implications. However, scientific analysis of the TMDL requires a slightly different approach than the Basin Plan.

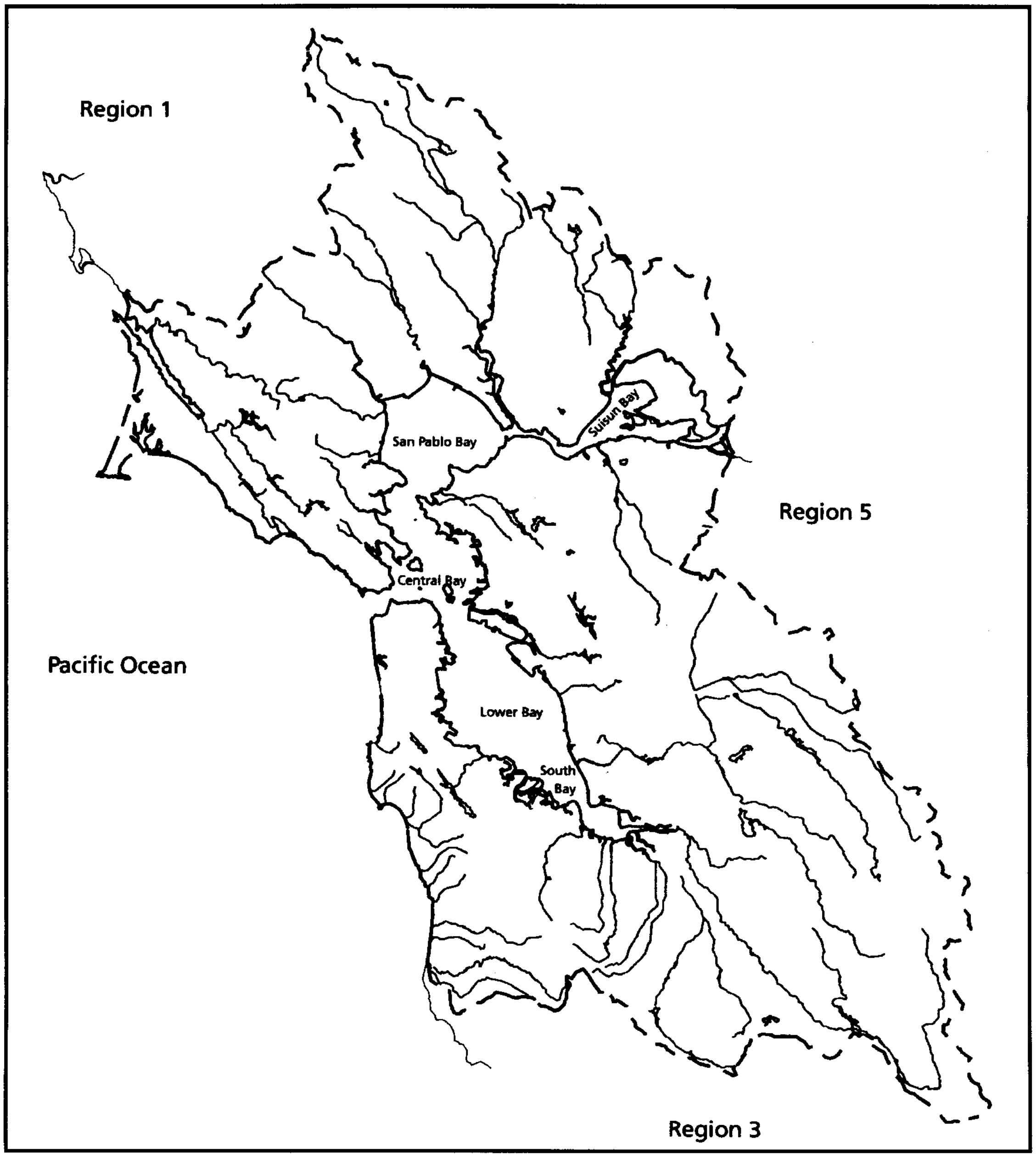


Figure 24: Segments of the San Francisco Bay Estuary as defined in the 1995 Basin Plan.

This TMDL analysis differs slightly from the 1995 Basin Plan. The segments of the estuary used in this report are shown in Figure 25, and their relevant physical processes are shown in Table 14. The segments are based on flow and circulation patterns of the estuary. The difference between the subdivisions used in this analysis and the Basin Plan segments is in the southern reach of the estuary. This report treats Lower South Bay, south of the Dumbarton Bridge, as a distinct segment, because of its more limited exchange with water to the north and unique hydrographic and geochemical processes. The segments referred to in the 1995 Basin Plan as "Lower Bay" and "South Bay" (north of the Dumbarton Bridge) are combined into one unit referred to as "South Bay" in this report.

The segmentation presented in this report is supported by our scientific understanding of trace element cycling in San Francisco Bay. In addition to the flow and circulation patterns, cluster and factor analysis[8] and mass balance calculations[49] using trace metal and nutrient data from San Francisco Bay confirm the distinctive properties of the bay segments delineated in Figure 25. Segments are linked by flow and mixing, so that the outputs from one segment affect the inputs from another.

Section 4.1.b Key Points:

- This analysis segments the Bay according to flow and circulation patterns.
- The segmentation used in this report differs slightly from the Basin Plan segments used to list impaired waterbodies.
- The segmentation scheme used in this report is supported by our scientific understanding of the Bay.

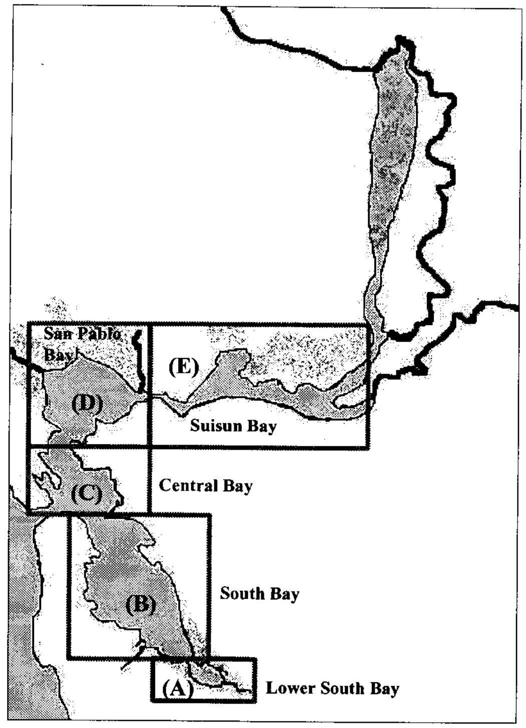


Figure 25: Segments of the San Francisco Bay Estuary used for this TMDL analysis. (A) Lower South Bay, south of the Dumbarton Bridge; (B) South Bay, between the Dumbarton Bridge and the San Francisco – Oakland Bay Bridge; (C) Central Bay, between the Richmond-San Rafael Bridge, the San Francisco-Oakland Bay Bridge, and the Golden Gate Bridge; (D) San Pablo Bay, Between the Richmond-San Rafael Bridge and the Carquinez Bridge; and (E) Suisun Bay and the Delta east of the Carquinez Bridge.

Segment	A	B	C	D	E
Name	Lower South Bay	South Bay	Central Bay	San Pablo Bay	Suisun Bay
Area ($m^2 \times 10^6$)	11	388	172	266	104
Average Depth (m)	3.0	5.0	15	5.0	3
Volume ($m^3 \times 10^6$)	34.0	1935	2615	1321	353
Watershed Area ($m^2 \times 10^6$)	2125	2684	274	2320	1526
Percent Developed Area in Watershed	36	29	73	17	28
Number of municipal dischargers	3	9	7	12	6
Number of industrial dischargers	1	0	1	3	9
Percent Influence by Sacramento River Inflow	1	10	90	100	100
Average annual runnoff volume ($m^3 \times 10^6$)	290	338	79	326	187
Average annual suspended load input (kg / yr x 10^6)	39	48	7.9	118	50
Mixing and circulation mechanism	Tidal	Tidal, wind	Tidal	Tidal, wind, fluvial	Tidal, wind, fluvial
Inputs from inoperative mercury mines?	yes	no	no	maybe	maybe

Table 14: Physical properties of bay segments in this TMDL analysis.

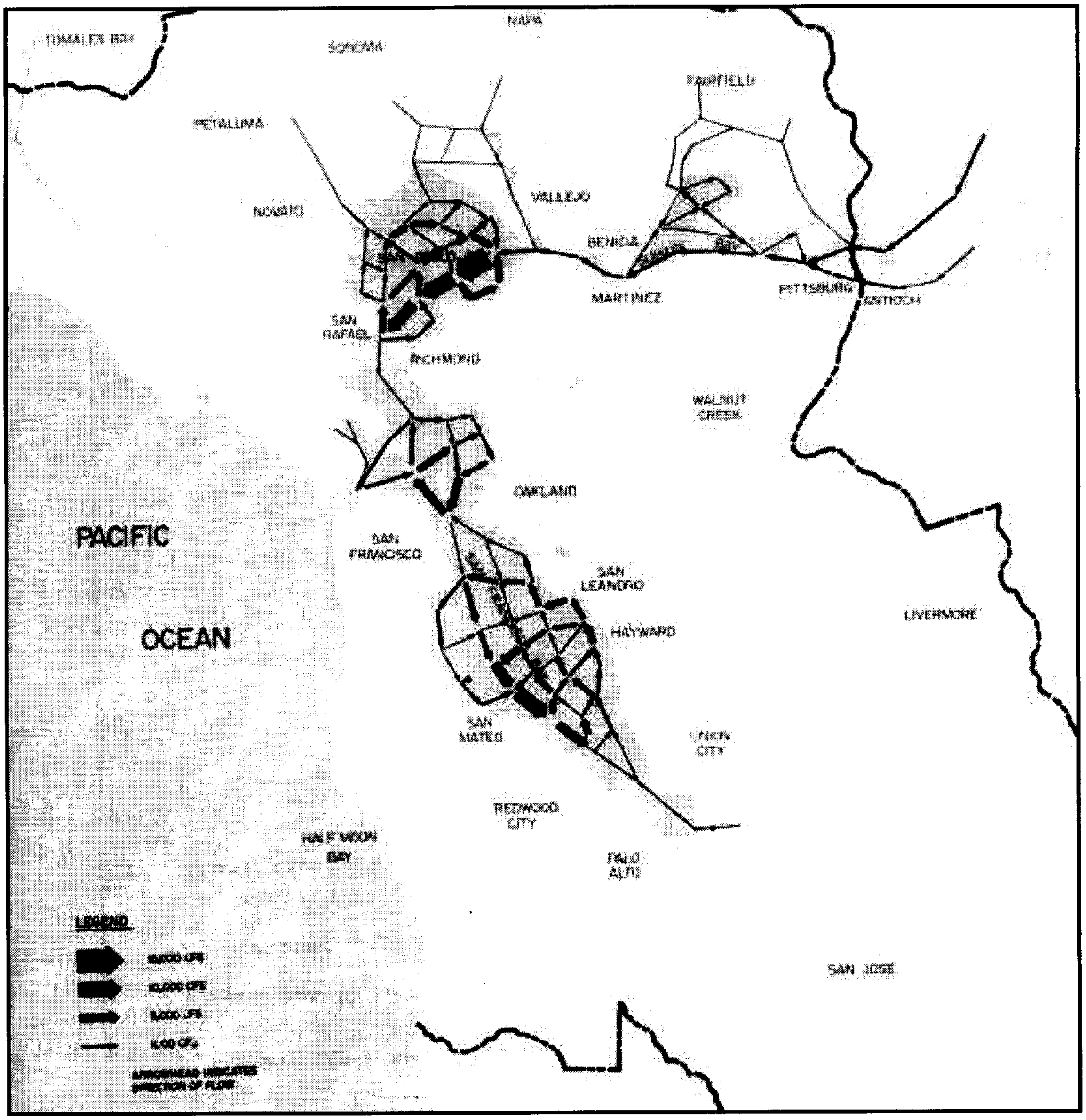


Figure 26: Schematic of general flow and circulation patterns of the San Francisco Bay Estuary. Taken from the 1975 Basin Plan.

4.1.c Sediments and mercury source assessment

We can calculate mercury loads from sediment loads, because mercury has a high affinity for particles. The median value for the distribution coefficient for mercury in San Francisco Bay is 10^7, meaning that at equilibrium there are 10 million atoms of particle-bound mercury for every atom that is dissolved. Loads from the Sacramento River and for benthic remobilization are calculated using the sediment budget for San Francisco Bay (Figure 27) and measurements of mercury concentrations in sediments. Watershed loads are calculated using estimates of sediment production for watershed subunits within the San Francisco Bay Region[50].

For box model and mass balance calculations, we make the steady-state approximation that the amount of sediment entering San Francisco Bay is roughly balanced by the amount leaving. We make this assumption for each segment of the Bay shown in Figure 25. However, not all segments are equally influenced by Central Valley drainage. Suisun Bay (Segment E) receives essentially all of the sediment leaving the Central Valley watershed. Incoming sediments mix with bedded sediments in Suisun Bay, and, over time, the amount of sediment exiting Suisun Bay is roughly equal to the amount entering. The same process happens in San Pablo Bay (Segment D): incoming sediments mix with bedded sediments, and eventually the amount passed into the Central Bay (Segment C) balances the amount entering San Pablo Bay.

In the Central Bay, the mixing dynamics of the estuary become extremely complex. We know that some of the sediments from Central Bay are exchanged by wind and tidal mixing over the San Bruno Shoals and into South Bay (Segment B), but we don't know how much. Likewise, we know that South Bay sediments are tidally mixed with Lower South Bay (Segment A) sediments, which would also introduce some fraction of the Central Valley sediments, but again we don't know how much. For this analysis, we will assume that 90% of sediments transported from the Central Valley through the northern reach to Central Bay exit via the Golden Gate, and 10% are exchanged into South Bay. Likewise, we assume that only 1% of the annual sediment load from the Central Valley affects Lower South Bay via wind and tidal exchange. These assumptions are listed in Table 14.

Sediment mass is converted to mercury mass using the concentration of mercury in sediments:

Equation 5

$$\text{Mass Hg (kg)} = \frac{\text{Mass Sediment (kg)} \cdot [\text{Hg}]_{\text{sed}} \text{ (mg Hg / kg sediment)}}{10^6 \text{ (mg Hg / kg Hg)}}$$

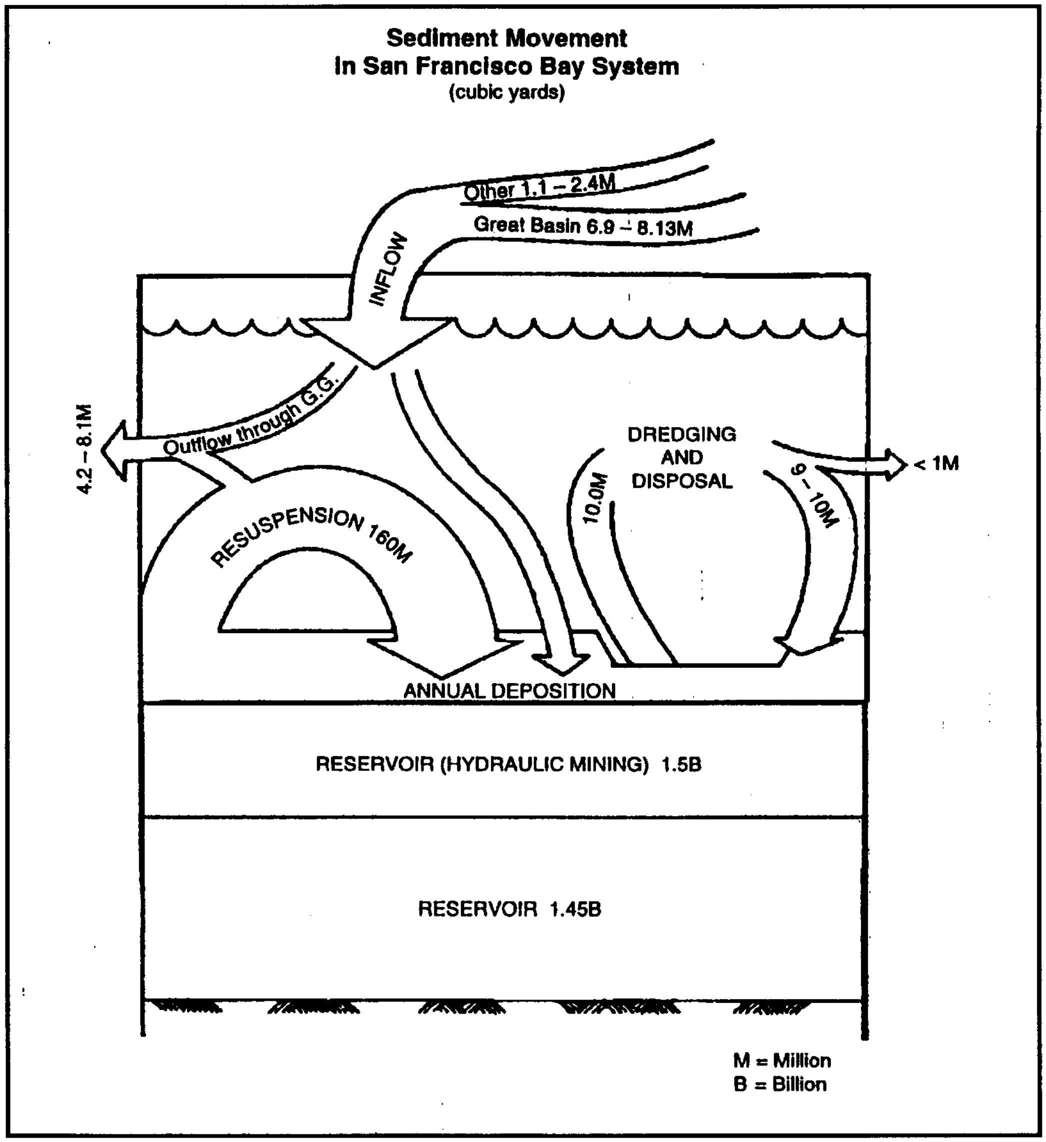


Figure 27: Sediment Budget for San Francisco Bay. Figure taken from LTMS report[51], based on original analysis by Krone (USGS)[31].

Sediment volumes are converted to sediment mass using the bulk density of sediments. When we talk about sediment volumes, we are talking about volume in-situ, including the water content of the sediments. When we convert sediment volumes to sediment masses, they are expressed as dry mass of sediment, because sediment mercury concentrations used in Equation 5 are normalized to dry weight. The LTMS sediment budget for San Francisco Bay (Figure 27) is defined in cubic yards (volume). The original data used to derive that sediment budget was expressed in mass units[31], and converted to cubic yards of *in-situ* sediment deposits (i.e, the volume including interstitial water) using a conversion factor of 33 lbs/ft^3 (=528.5 kg/m3, or 0.53 g/cc). Therefore, to convert from LTMS sediment budgets to dry mass of sediment, we use the conversion factor in Equation 6:

Equation 6

$$\text{Mass Dry Sediment (kg)} = \frac{\text{Volume Wet Sediment (yd}^3\text{)}}{1} \cdot \frac{1\ \text{m}^3}{1.308\ \text{yd}^3} \cdot \frac{528.5\ \text{kg}}{1\ \text{m}^3}$$

The conversion factor in Equation 6 assumes a relatively high proportion of water in the bulk sediments. The density of dry aluminosilicate sediments is 2650 kg/m^3, so the conversion in Equation 6 implies a water content of ≈80% (528.5 / 2650 = 0.2). Equation 6 is only appropriate for converting sediment volumes from the LTMS budget to sediment masses, because that was the factor used to derive volumes from masses. Table 15 shows the annual sediment budget for San Francisco Bay in millions of kg per year, calculated using Equation 6.

	Best Estimate	Max	Min
Sediments from Central Valley	3036	3285	2788
Sediments from Local Watersheds	707	970	444
Dredging and Disposal	3838	4041	3636
Outflow Through Golden Gate	2485	3273	1697
Wind Wave Resuspension	64648	64648	64648

Table 15: Annual sediment budget for San Francisco Bay, expressed in kg x 10^6 per year. Calculated from data in Figure 27 using Equation 6. Best estimate is average of maximum and minimum values.

In other calculations, we use sediment volumes derived from the area of a waterbody and the depth of the bedded sediments available for resuspension (the active depth). Equation 7 converts bedded wet sediment volumes to dry sediment masses, assuming a water content of 50%. A water content of 50% is more appropriate to San Francisco Bay bedded sediments in the upper 1 meter. The reason that the conversion factor used in the

LTMS budget is different is likely because that the dry unit weight conversion used by Krone[31] refers to dredged material[52]. Dredged sediments typically have higher water content than bedded sediments.

Equation 7

$$\text{Mass Dry Sediment (kg)} = \frac{\text{Volume Wet Sediment (m}^3\text{)}}{1} \cdot \frac{\text{50 kg dry sediment}}{\text{100 kg wet sediment}} \cdot \frac{\text{2650 kg}}{1\ \text{m}^3}$$

Section 4.1.c Key Points:

- We can calculate many mercury loads from sediment loads, because mercury sticks to particles.
- The sediment budget for San Francisco Bay helps quantify sediment loads from the Central Valley and sediment remobilization within the Bay.
- The Coastal Watershed Mass Loading Project report helps quantify sediment loads from runoff within the watershed.
- There are equations to convert sediment volume to sediment mass.
- There is an equation to convert sediment mass to mercury mass

4.2 Watershed loading from the Central Valley

The Central Valley is the dominant sediment source to San Francisco Bay, bringing 2.8-3.8 billion kg of sediment per year into the estuary. The mercury concentration of suspended sediment brought into the estuary has been calculated three ways in this report:

i) From the slope of the regression line in a plot of $[Hg]_{tot}$ in water vs. TSS (Figure 16).
ii) From the median calculated concentration of mercury in suspended particles (Figure 17)
iii) From the geometric mean of benchmark soils in the Central Valley drainage basin (Table 9).

All three methods show that 0.2 µg/g is a reasonable representative concentration of mercury in sediments transported from the Central Valley. Data from the Sacramento River Mercury Control Planning Project [53]show that the average concentration of mercury in suspended particles (<0.2 µm) is 0.30 – 0.35 µg/g. A study by the Central Valley Regional Board [54] also shows mercury concentrations of 0.20 – 0.35 in suspended particles.

From these five independent assessments, we get a range of 0.20 – 0.35 µg/g for the concentration of mercury in suspended sediments exported from the Central Valley drainage basin. Substituting this range into Equation 5, and using the maximum and minimum values for Central Valley sediment exports (Table 15), yields a range of 558-1150 kg mercury per year entering the estuary from the Central valley, with a best estimate of 607 kg per year. This agrees with a previous assessment[54] showing that the Central Valley brought ≈800 kg of mercury to the estuary from 1 May 1994 to 30 April 1995.

Section 4.2 Key Points:

- A good estimate of mercury concentration in sediment exported from the Central Valley is 0.20 – 0.35 µg/g
- We estimate that 558-1150 kg of mercury enters the Bay from the Central Valley each year.

4.3 Watershed sources within the San Francisco Bay Region

This section summarizes loadings from watershed sources within the San Francisco Bay Region. The processes controlling background watershed inputs are discussed in section 4.3.a. Section 4.3.b quantifies inputs from one watershed, the Guadalupe River, that contributes mercury loadings significantly above background levels. Section 4.3.c briefly discusses the potential importance of other, smaller sites within the watershed that have known historic mercury problems.

4.3.a Watershed background load

The background load of mercury from a watershed comes from mercury in the parent rock and from atmospheric deposition of mercury. The watershed background of total mercury can be estimated from sediment production rates within a watershed. The Coastal Watershed Mass Loading Project [50] report provides a recent summary of watershed sediment loadings based on land use patterns, vegetative cover, hill slope, and annual rainfall. The watershed subunits from that report are shown in Figure 28. The annual mass of sediment produced in each watershed subunit is listed in Table 16, along with the associated mercury mass load estimates.

Mass loadings of mercury are calculated from sediment loadings by making reasonable assumptions about the average concentration of mercury in sediments. Since mercury in watershed sediments is affected in part by atmospheric inputs, this calculation incorporates the atmospheric deposition pathway. The atmospheric deposition component can also be evaluated separately from deposition rates and land use patterns (Section 4.4).

The median value of mercury from bay tributaries and margins is 0.4 μg/g [55]. The calculations in Table 16 assume that mercury concentrations in sediments range from half of this value (0.2 μg/g) to twice this value (0.8 μg/g), which is comparable to the range observed in recent surveys [56].

The Guadalupe River watershed has much higher mercury concentrations in sediments than other watersheds in our Region. As recently as 1998, sediments in the lower Guadalupe River were shown to have at least 1 μg/g mercury [27], and at times concentrations as high as 10 μg/g have been measured [28]. For this analysis we assume a range of 1 – 10 μg/g. The next section presents a more detailed analysis of loadings from the Guadalupe River watershed.

Watershed loads will vary with annual rainfall. High rainfall years produce more sediment, which will lead to higher mercury loads. Table 16 accounts for this explicitly by reporting the mercury loads for the mean, 10'th percentile, and 90'th percentile of rainfall years. The average value is most appropriate for a long-term watershed management plan for mercury. However, the upper and lower extremes are useful for characterizing seasonal variation and critical conditions (Section 7).

Overall, annual watershed background loadings to the entire Bay are 32-155 kg during dry years, 58-278 kg during normal years, and 90-463 kg during wet years (Table 16). There are two sources of uncertainty driving the observed ranges: the actual sediment production from each watershed subunit, and the true concentration of mercury in sediments. Reducing uncertainty in the characteristic concentration of mercury in sediments from each watershed is a high priority, because the TMDL target is based on sediment mercury concentrations.

Section 4.3.a Key Points:

- Watershed background loads come from mercury in the parent rock of the watershed and atmospheric deposition of mercury.
- We estimate mercury watershed load based on sediment loads and mercury concentrations in sediments.
- The median value of mercury in sediments from Bay tributaries and margins is 0.4 μg/g, so we assume a range of 0.2 – 0.8 μg/g for mercury in watershed sediments.
- Sediments from the Guadalupe River watershed have concentrations in the range of 1-10 μg/g.
- Sediment loads vary with rainfall, so watershed loads of mercury have to be referenced to annual rainfall amount.
- Overall, watershed loads are 32-155 kg during dry years, 58-278 kg during normal years, and 90-463 kg during wet years.

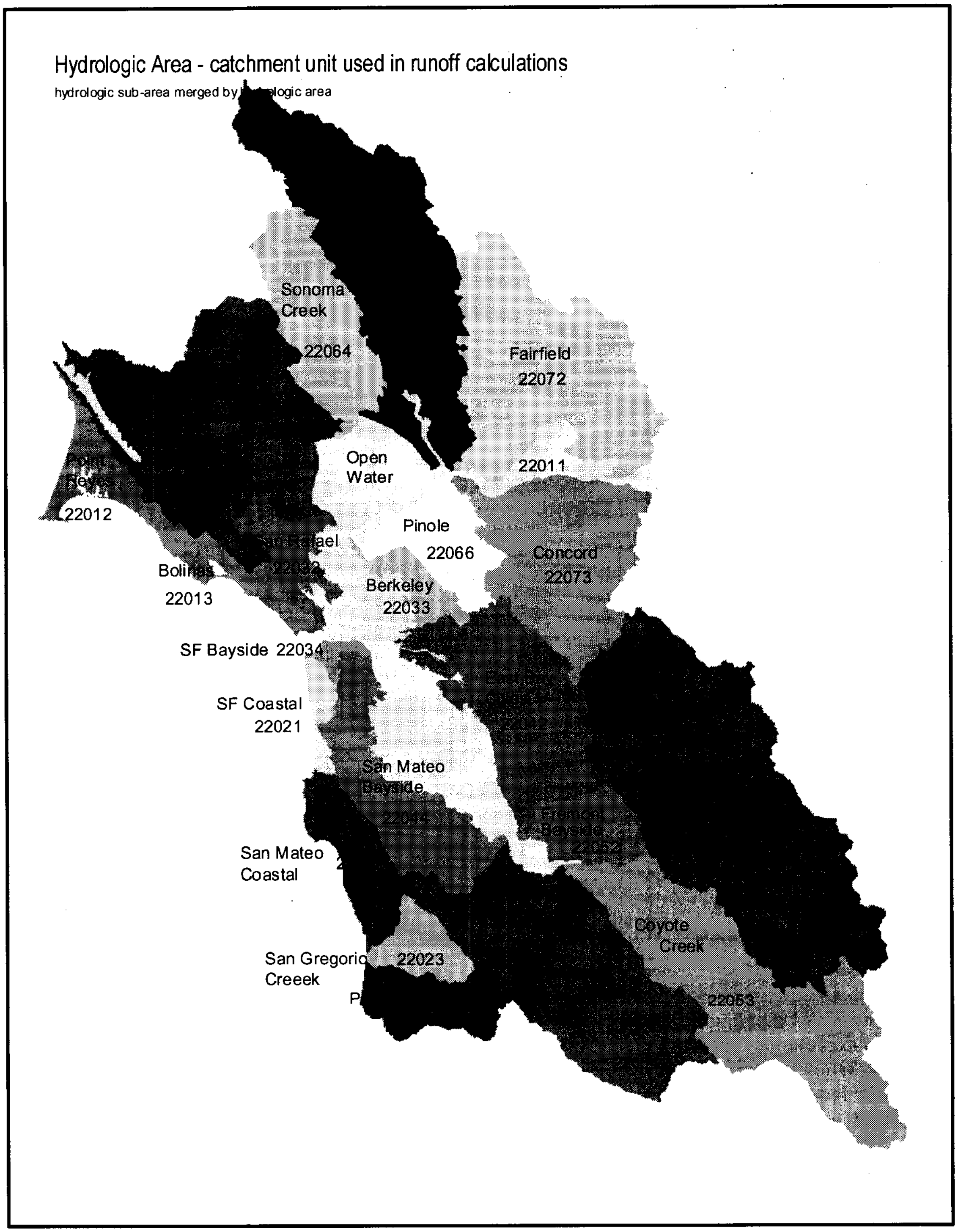


Figure 28: Catchment units used in determination of watershed loads of flow and suspended sediment into each Bay segment. Image taken from SFEI's Coastal Watershed Mass Loading Project report[50].

Box Model Segment	Hydrologic area code	Hydrological area name	Annual TSS (kg x 10^6) 10'th %'tile	avg.	90'th %'tile	Minimum annual mercury load (kg) for a given rainfall year 10'th %'tile	avg.	90'th %'tile	Maximum annual mercury load (kg) for a given rainfall year 10'th %'tile	avg.	90'th %'tile
Lower South Bay (Segment A)											
A	220520	Fremont Bayside	2.2	3.7	4.9	0.4	0.7	1.0	1.8	3.0	3.9
A	220530	Coyote Creek	6.6	15.8	15.3	1.3	3.2	3.1	5.3	12.7	12.3
A	220540	Guadalupe River	4.3	7.4	16.9	4.3	7.4	16.9	42.9	73.9	168.7
A	220550	Palo Alto	6.0	12.1	23.9	1.2	2.4	4.8	4.8	9.7	19.1
		Subtotal for Segment A	19	39	61	7	14	26	55	99	204
South Bay (Segment B)											
B	220420	East Bay cities	7.4	14.1	20.4	1.5	2.8	4.1	5.9	11.2	16.4
B	220430	Alameda Creek	10.9	24.2	29.9	2.2	4.8	6.0	8.7	19.3	23.9
B	220440	San Mateo - Bayside	5.2	9.6	13.2	1.0	1.9	2.6	4.2	7.7	10.6
		Subtotal for Segment B	24	48	64	4.7	10	13	19	38	51
Central Bay (Segment C)											
C	220320	San Rafael	3.0	4.3	7.3	0.6	0.9	1.5	2.4	3.4	5.9
C	220330	Berkeley	1.7	2.7	4.4	0.3	0.5	0.9	1.4	2.2	3.6
C	220340	San Francisco - Bayside	0.5	0.8	1.2	0.1	0.2	0.2	0.4	0.7	0.9
		Subtotal for Segment C	5.2	7.9	13	1.0	1.6	2.6	4.2	6.3	10
San Pablo Bay (Segment D)											
D	220620	Novato	3.6	7.5	11.7	0.7	1.5	2.3	2.9	6.0	9.3
D	220630	Petaluma River	13.1	23.7	30.0	2.6	4.7	6.0	10.5	18.9	24.0
D	220640	Sonoma Creek	19.0	28.9	44.0	3.8	5.8	8.8	15.2	23.2	35.2
D	220650	Napa River	26.8	53.0	87.7	5.4	10.6	17.5	21.5	42.4	70.2
D	220660	Pinole	2.5	4.5	5.1	0.5	0.9	1.0	2.0	3.6	4.1
		Subtotal for Segment D	65	118	178	13	24	36	52	94	143
Suisun Bay (Segment E)											
E	220721	Fairfield (220721)	3.4	6.4	7.3	0.7	1.3	1.5	2.7	5.1	5.9
E	220722	Fairfield (220722)	1.7	3.7	3.7	0.3	0.7	0.7	1.4	3.0	3.0
E	220723	Fairfield (220723)	17.3	27.0	37.0	3.5	5.4	7.4	13.9	21.6	29.6
E	220724	Fairfield (220724)	0.4	0.6	0.9	0.1	0.1	0.2	0.3	0.5	0.7
E	220731	Concord (220731)	4.3	6.4	10.6	0.9	1.3	2.1	3.5	5.1	8.5
E	220732	Concord (220732)	1.9	2.9	4.7	0.4	0.6	0.9	1.5	2.3	3.8
E	220733	Concord (220733)	1.4	2.1	2.8	0.3	0.4	0.6	1.1	1.7	2.3
E	220734	Concord (220734)	0.7	1.0	1.6	0.1	0.2	0.3	0.5	0.8	1.3
		Subtotal for Segment E	31	50	69	6.2	10	14	25	40	55
		Total for all segments	144	262	385	32	58	90	155	278	463

Table 16: Sediment and mercury load estimates for watershed subunits in the San Francisco Bay Region. Minimum and maximum mercury loads are based on minimum and maximum concentrations expected for mercury concentrations in sediments (0.2 – 0.8 µg/g for all watersheds except the Guadalupe River, 1-10 µg/g for the Guadalupe River). Average, 10'th percentile, and 90'th percentile loadings refer to loadings predicted for corresponding average and extreme rainfall years. Flow and TSS data taken from SFEI's Coastal Watershed Mass Loading Project report[50] .

4.3.b The Guadalupe River Watershed

There are two fundamental questions related to assessing and reducing mercury loads from the Guadalupe River watershed (Figure 29):

i) How much sediment is transported from the watershed into Lower South Bay?
ii) What is the average (or median) mercury concentration of that sediment?

The Coastal Watershed Mass Loadings Project [50] estimates that the Guadalupe River discharges an annual average of 7.4 million kg of sediment. This is close to the estimates of the South Bay Watershed Management Initiative, which reported 7.0 million kg annually [57]. Both estimates used annual rainfall, terrain, and land use characteristics to model stormwater sediment loadings. The former report includes area above the reservoirs, the latter does not. This may account for some of the difference between the two estimates; reservoir releases into the Guadalupe River watershed amount to 154,000 kg annually from the Lexington, Guadalupe, Almaden, and Calero Reservoirs.

These modeling estimates are lower than previous USGS calculations. Using flow data from the gauging station in the Lower Guadalupe River at San Jose (USGS Station 11169000) and sediment transport curves, Porterfield [32] estimates an average discharge rate of 223 tons of sediment per day in 1957-1959, and an average rate of 129 tons per day in 1909-1959, corresponding to annual sediment discharge rates of 42 million and 74 million kg, respectively.

Sediment discharge from the Guadalupe River is episodic. In eleven years (1957-1966), total sediment discharge was 386,000 tons, but approximately 87% of that (336,000 tons) was discharged in two storm periods, over a total of eighteen days. The corresponding annualized average is 32 million kg of sediment. We have to express sediment loads as annualized averages to provide the required components of a TMDL analysis. However, to implement sensible, watershed-based solutions we will have to keep in mind the episodic nature of the watershed loads.

In summary, land-use models predict annual sediment loads averaging 7 million kg, whereas flow – sediment calculations suggest annual loads on the order of 32-74 million kg. The sediment transport dynamics of the Guadalupe River watershed need to be better defined, but the data available are useful for making first-order load and mass balance calculations for Lower South Bay. We will use 32 million kg as an upper estimate of annual sediment loading, and 7 million as a lower estimate, and 154,000 kg as an estimate of the sediment loads from reservoirs in the New Almaden District.

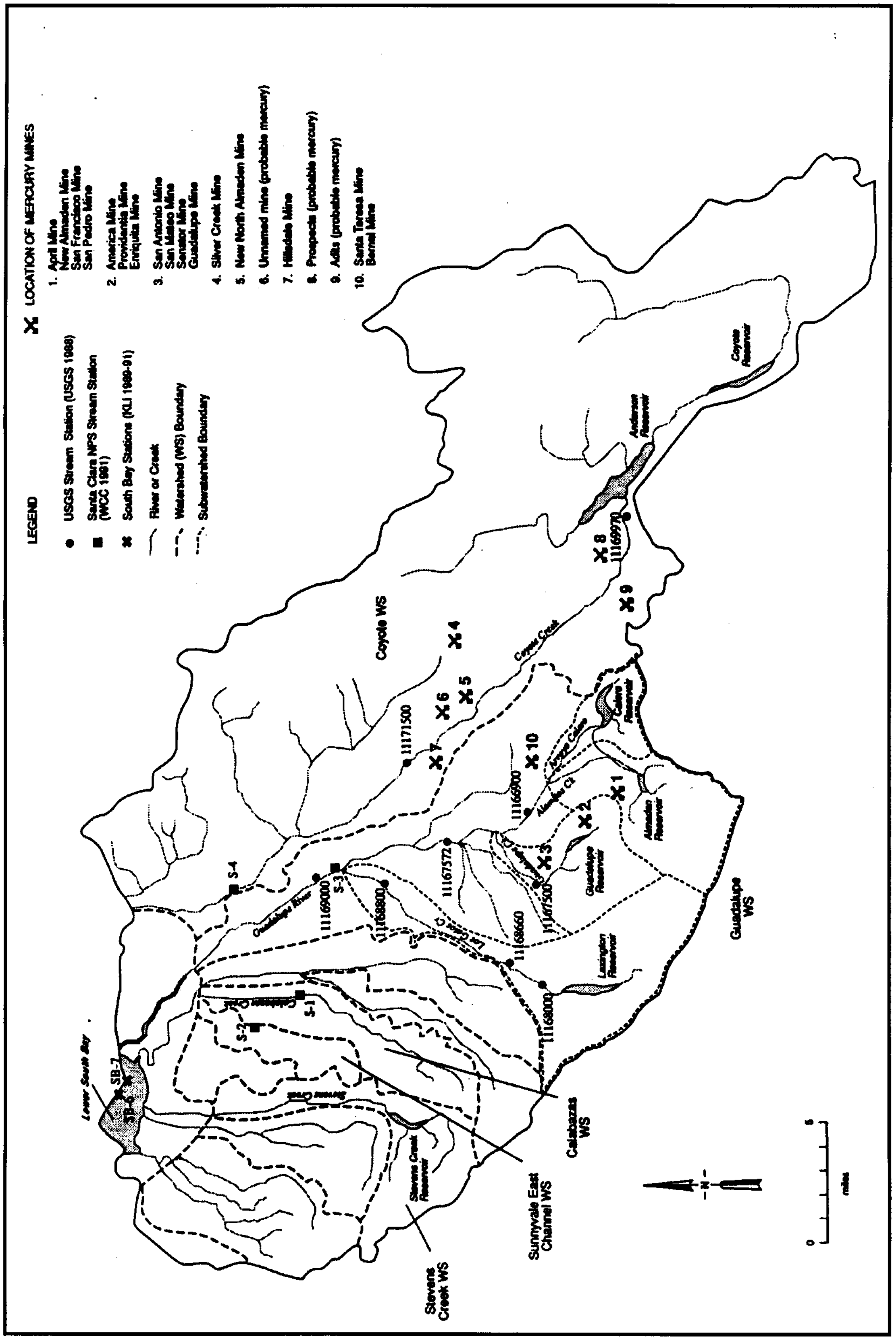


Figure 29: Map of Guadalupe River and adjacent watersheds. Image from report by Santa Clara Valley Nonpoint Source Control Program[28].

The mercury concentrations found in those sediment loads increase along a gradient leading towards the New Almaden mining district in the upper watershed (Figure 30). To estimate mercury loads from the reservoirs alone, we use sediment concentrations just below the reservoir, and annual sediment discharge rates from reservoir releases. To determine mercury loads into Lower South Bay, we use sediment concentrations from the lower Guadalupe River and sediment loadings from the entire watershed.

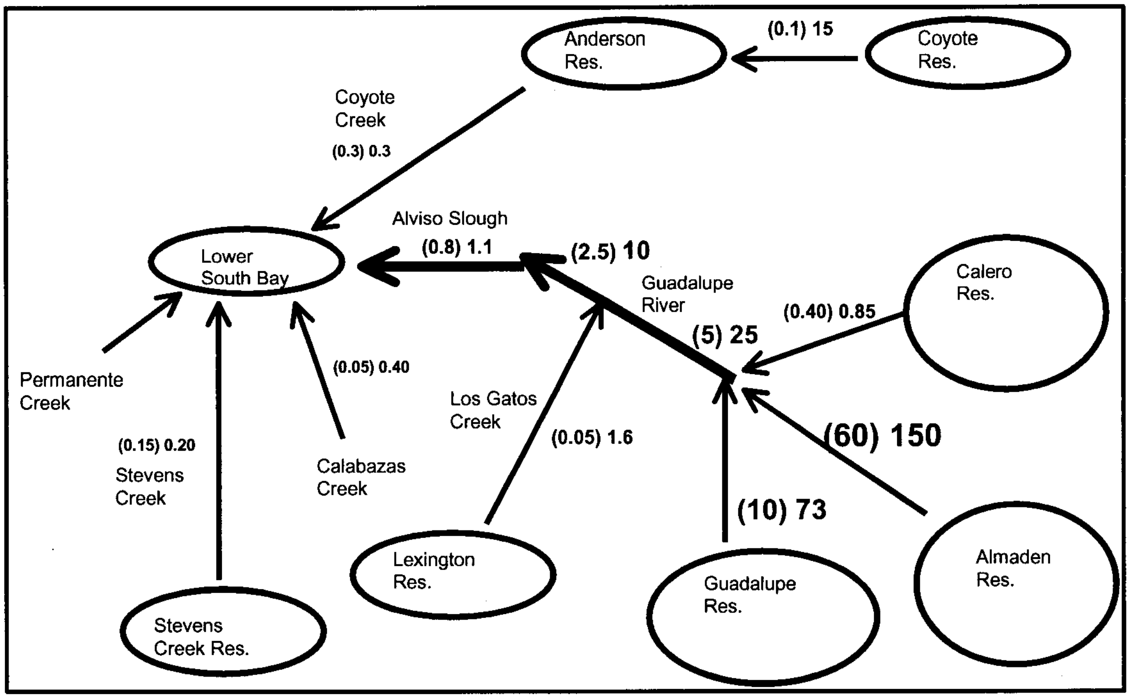


Figure 30: Schematic summarizing mercury concentrations (µg/g) in the Guadalupe River watershed and adjacent watersheds. Figured constructed using data from the RMP [1] and from the Santa Clara Valley Nonpoint Source Control Program [28]. Numbers in parentheses show medians, numbers without parentheses show maximums. Font size increased for larger concentrations. Arrows indicate flow from reservoirs and tributaries into the Guadalupe River and Lower South Bay.

Mercury concentrations in sediments from the lower Guadalupe River are consistently around 1 µg/g. This was first reported in 1971 [55], confirmed in 1992 [28], and more recently by the RMP and by the USGS [27]. In the Guadalupe River reach in downtown San Jose, sediments ranged from 1 to 10 µg/g, with a median value of 2.5 µg/g . So a reasonable range for mercury concentrations in bedded sediments in the lower Guadalupe River is 1 – 2.5 µg/g. However, it not certain that bedded sediments are the best approximation for mercury concentrations in during peak flows, when transport from the upper watershed is enhanced. It is possible that the upper extreme, 10 µg/g, is a more representative concentration of sediments transported into Lower South Bay during peak flows. For this analysis, we assume a range of 1 – 10 µg/g, with a best estimate of 2.5 µg/g. For calculating loads from the upper watershed to the lower watershed, we use the median sediment concentrations downstream of each reservoir (Figure 30). The load calculations are summarized in Table 17 and Table 18.

	Annual Sediment ($x10^6$ kg)	[Hg] (µg/g)	**Annual Hg (kg)**
Best Estimate	20	2.5	**49**
Max	32	10	**320**
Min	7	1	**7**

Table 17: Sediment and mercury loadings from the Guadalupe River watershed into Lower South Bay.

	Annual Sediment (kg)	[Hg] (µg/g)	**Annual Hg (kg)**
Best Estimate	153969	5	**0.8**
Max		25	**3.8**
Min		2.5	**0.4**

Table 18: Sediment and mercury loadings from reservoir (Lexington, Almaden, Calero, and Guadalupe) releases in the upper Guadalupe River watershed.

There is a big difference between the mercury mass released from the reservoirs in the upper watershed and the mercury mass released into Lower South Bay. Comparison of Table 17 with Table 18 shows that 98% of the mercury in the watershed is mobilized below the reservoirs. Much of this load may be related to known erosion and sedimentation problems in the upper reaches of Almitos, Calero, and Guadalupe Creek [58]. However, the watershed below the reservoirs has undergone extensive urbanization over the past thirty years. We require better estimates of sediment loads and mercury concentrations in sediments conveyed by stormwater outfalls to identify the most effective control measures for mercury loads from this watershed.

Section 4.3.b Key Points:

- Hydrologic models suggest that 7 million kg of sediment is transported from the Guadalupe River watershed into Lower South Bay.
- In contrast flow-sediment calculations suggest sediment loads more like 32-74 million kg per year from the Guadalupe River.
- The concentration of mercury in that sediment is 1-10 µg/g, with a best estimate of 2.5 µg/g.
- The resulting load is 49 kg mercury per year, based on an estimated sediment flux of 20 million kg per year.

4.3.c Toxic hot spots

There are several cleanup sites around the margins of the Bay that are known to have elevated mercury concentrations in sediments. These sites have been impacted by industrial operations, including shipping, paint manufacturing and chlor-alkali processing. Ongoing inputs to these sites have been stopped, and some improvement has been observed. For instance, Islais Creek sediments had 6 μg/g mercury in 1971; today, sediments from that site have ≈1 μg/g. From the perspective of total loadings, extant toxic cleanup sites appear to be a small portion of the mercury problem in the Bay.

However, we will direct mercury remediation efforts using the dissolved methylmercury target, because the Bay margins are very likely areas of enhanced methylation. At present, our understanding of the methylmercury mass balance for the estuary is not sufficient to establish load allocations for toxic cleanup sites. During the first phase of the TMDL, we will require information from responsible parties on the net contribution of methylmercury from mercury-contaminated sites into the Bay, including an assessment of how those methylmercury inputs compare to ambient processes. We may also require additional remediation or mitigation in instances where mercury contamination causes exceedance of the 0.05 ng/L dissolved methylmercury target in waters of San Francisco Bay.

Section 4.3.c Key Points:

- Hydrologic models suggest that 7 million kg of sediment is transported from the Guadalupe River watershed into Lower South Bay.
- In contrast, flow-sediment calculations suggest sediment loads more like 32-74 million kg per year from the Guadalupe River.
- The concentration of mercury in that sediment is 1-10 μg/g, with a best estimate of 2.5 μg/g.
- The resulting load is 49 kg mercury per year, based on an estimated sediment flux of 20 million kg per year and a mercury concentration of 2.5 μg/g.

4.4 Atmospheric Sources

The problem of atmospheric mercury sources can be divided into four questions:

i) How much mercury is released regionally into the atmosphere?
ii) How much mercury is deposited?
iii) How much of deposited mercury is transferred to the aquatic ecosystem?
iv) What is the biological availability of deposited mercury?

The first two questions are accessible through direct measurements. The latter two require both modeling and experimental approaches. While we need better science information relevant to each question, we do know enough right now to make sensible policy recommendations regarding control of air sources.

4.4.a Sources to atmosphere

There are three general classes of mercury emissions to the atmosphere:

i) Stationary combustion sources (incineration, calcining, manufacturing)
ii) Mobile combustion sources (cars, trucks, and ships)
iii) Area-wide non-combustion sources (fluorescent lamps, mines, microbial activity)

stationary sources

Stationary combustion sources of mercury may amount to approximately 250 kg per year throughout the Bay Area. This figure is based on a survey of air emission permits issued by the Bay Area Air Quality Management District (BAAQMD). Only about 10% of this total (25 kg per year) is based on actual source testing; the remainder has been estimated by BAAQMD using general emission factors, which have a high degree of uncertainty.

mobile combustion sources

We estimate that mobile combustion sources release 10-20 kg mercury per year in the Bay Area. This was estimated two ways. The U.S. EPA provides an emission factor of 1.3 μg mercury released per kilometer driven, assuming 16% of the vehicles are diesel trucks. That estimate comes from a 1977 study, which took place before much more stringent tailpipe emission controls on gasoline and diesel vehicles were required. Assuming 5,000,000 vehicles in the Bay Area and an average of 15,000 miles driven annually per vehicle, we get an upper estimate ≈150 kg of mercury emission per year using the older vehicular emission factor. This is probably tenfold or more higher than contemporary vehicular emissions of mercury. Alternatively, scaling statewide consumption rates of gasoline, diesel, bunker oil, and aviation gasoline to the Bay Area population, we get an estimate of 9-21 kg per year for all mobile sources. Diesel is the dominant mercury source among these, because it has a relatively high emission factor for combustion (0.86 lbs Hg / million gallons). The Bay Area Stormwater Management Agencies Association (BASMAA) is currently investigating mercury concentrations in fuels to develop better loading estimates for mobile sources.

area-wide non-combustion sources

Breakage of fluorescent light bulbs in the Bay Area may contribute 10 to 130 kg/yr as air emissions. Mercury is also in other types of electric lamps, namely mercury vapor, metal halide, and high-pressure sodium lamps. Although the mercury mass per bulb in these lamps is higher than in fluorescent bulbs, their lower usage rates and breakage rates yield much lower emission estimates of from 0.07 to 1.6 kg/yr[59].

There are two types of bulbs most used in commerce, T12 and T8. T12s currently dominate the fluorescent lamp population[60]. T8 are high energy efficiency bulbs and contains about half the mercury as T12 bulbs. The precise mercury content varies with manufacturer and with the date of manufacture. Currently, T12 bulbs contain on average 21 mg mercury per bulb; T8s, 10 mg mercury per bulb. Bulbs manufactured prior to 1996 to 1999 may contain 50 percent more mercury. About 0.2 percent of the mercury is in its elemental form. The remainder is in the divalent form attached to calcium phosphate powder.

The U.S. EPA estimated a national emission of between 399 to 1652 kg of mercury from fluorescent lamp breakage for the year 2000. This estimate is from a numeric model that predicts the emissions over time as newer bulbs with lower mercury content replaces older bulbs with higher mercury content. Other factors that change the quantity and type of bulbs used over time are also considered in the model. For example, they used yearly estimates of the commercial floor space lit with fluorescent lamps and assumptions about lamp lifetimes and delamping rates to derive varying rates for wasting of lamps. In general, the model shows that the emissions decrease over time until 2006 when they start a slight increasing trend due to the expected growth of commercial space requiring fluorescent lighting.

The U.S. EPA's model also factors in different levels of emissions from various methods of disposal: recycling, landfilling, and incineration. It uses a 10 percent recycle rate and assumes specific percentages of bulbs that reach municipal landfills versus hazardous waste landfills.

We derive a Bay Area emission estimate of 9.5 to 39 kg/yr by scaling the above national emissions to the Bay Area population. This may be an under-estimate, however, because the U.S. EPA model assumes that only mercury vapor (1%-7% of the total) is lost from lamp breakage. A more recent study that used air measurements in dumpsters with broken lamps suggests that much higher percentages (20%-80%) are lost through volatilization[61;62].

There are about 2.2 mercury containing lamps per person manufactured each year nationally, and about 12 percent of the lamps are ultimately recycled (personal communication with Paul Abernathy, Executive Director of the National Lamp and Mercury Recyclers Association). Assuming the difference equals the disposal rate, Bay Area residents and businesses discard 13 million fluorescent bulbs per year to landfills. Assuming 50 percent (mean of 20 to 80 percent) of the total mercury in a lamp is lost from breakage, at 20 mg of mercury per bulb, as much as 130 kg/yr of mercury may be released from bulb breakage in the Bay Area. This will serve as the upper bound for the emission estimate from lamps, while the U.S. EPA estimate of 10 kg/yr will serve as the lower bound.

Mercury is also volatilized from soil, natural mercury deposits, surface mining wastes, and from the ambient surface waters. There are ways to directly measure evasive fluxes[63-65]. There is no data available for the Bay Area, but we can make some reasonable estimates. Using a range of mercury evasion rates observed in lakes [66]and the surface area of the Bay, we estimate that the flux of elemental mercury out of Bay waters into the atmosphere is between 2 and 25 kg per year. The flux of mercury from the contaminated soils and waste rock of the New Almaden mining district is unknown, but could be of the same magnitude as evasion from the Bay waters.

In summary, inputs of mercury to the atmosphere in the San Francisco Bay region total approximately 370 kg per year: ≈250 kg from stationary combustion sources, ≈20 kg from mobile combustion sources, and ≈100 kg from area-wide non combustion sources. Some of these sources may be readily controllable, others may be more difficult. One of out highest priorities in the first phase of the TMDL is to better quantify these sources, identify possible control measures and associated costs, and establish the linkage between inputs to the atmosphere, and the aquatic ecosystem. The next two sections discuss one piece of that linkage: the magnitude of mercury inputs from the atmosphere into Bay waters.

4.4.b Direct deposition rates

What goes up must come down, but where? The RMP has just begun measuring mercury deposition rates in the Bay Area. At present, we can only estimate deposition rates by assuming that they are somewhere between the global background deposition rate (2-5 $\mu g/m^2/yr$)[67] and the highest deposition rates observed in urban areas of the United States (10-26$\mu g/m^2/yr$) (Figure 31).

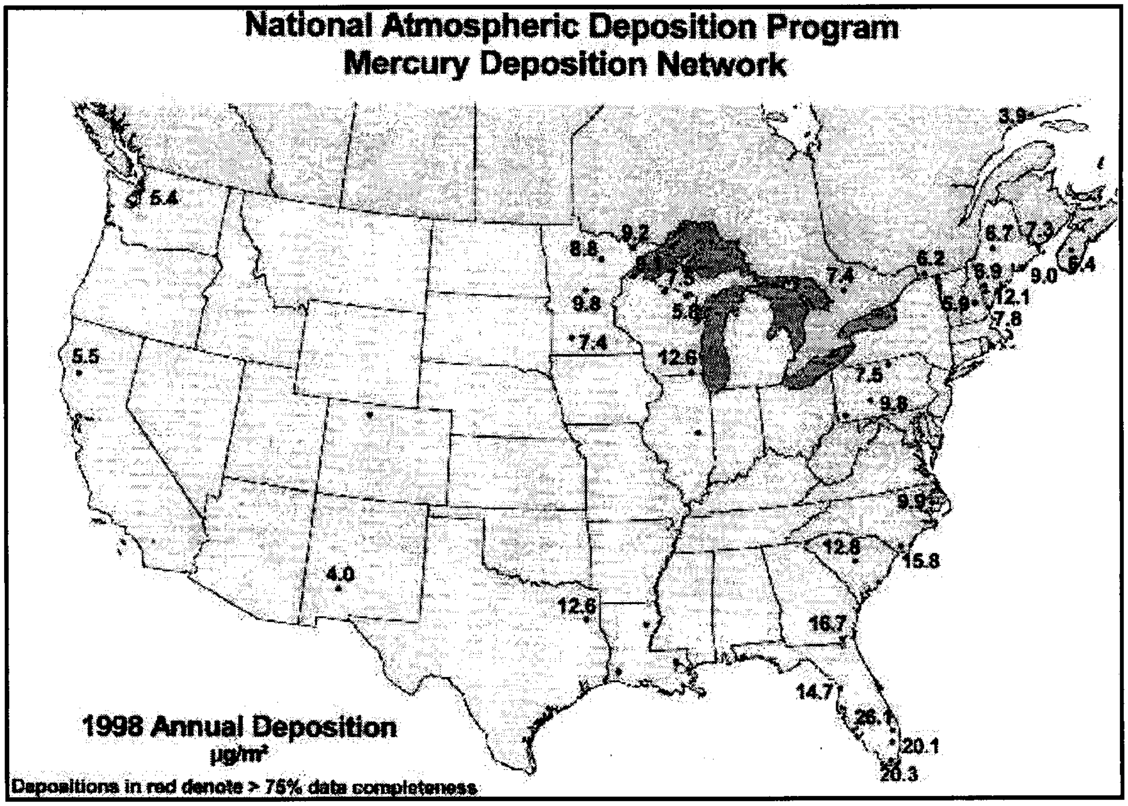


Figure 31: Annual atmospheric deposition rates of mercury in the United States.

Applying the range of deposition rates observed in urban areas (10-26 $\mu g/m^2/yr$) to the area of the entire San Francisco Bay watershed (10^{10} m^2, excluding the Central valley, but including surface area of the Bay), we get an annual fallout rate of 102-265 kg per year. At 2-5 $\mu g/m^2/yr$, inputs due to the global background amount to 20-51 kg per year in the entire watershed, so inputs from regional deposition must amount to 51-245 kg per year, or 14%- 66% of total releases to the atmosphere. The remaining fraction (34%-86%) of regional inputs to the atmosphere either falls out in the Central Valley, deposits in more remote watersheds, or becomes part of the global background.

Atmospheric fallout in the Bay Area reaches the Bay by two pathways: direct deposition onto the entire Bay, and indirect deposition onto surrounding land mass that enters the Bay via runoff. Direct deposition amounts to 11-28 kg per year for urban deposition rates, and 2-5 kg per year for background deposition rates. Those totals are summarized by Bay segment in Table 19. The next section discusses input rates from fallout on the surrounding watershed into Bay waters.

Bay Segment	Segment area, including mudflats ($m^2 \times 10^6$)	Global Background (low)	Global Background (high)	Urban deposition (low)	Urban Deposition (high)
A - Lower South Bay	41	0.1	0.2	0.4	1.1
B - South Bay	438	0.9	2.2	4.4	11.4
C - Central Bay	180	0.4	0.9	1.8	4.7
D - San Pablo Bay	307	0.6	1.5	3.1	8.0
E - Suisun Bay	110	0.2	0.5	1.1	2.9
Total	1075	2.1	5.4	10.7	27.9

Table 19: Direct atmospheric deposition (kg/yr) in Bay segments based on urban deposition rates and global background rates. The urban deposition rates are presumed to include both regional and global sources.

4.4.c The coupled processes of atmospheric deposition and stormwater runoff

Atmospheric deposition of mercury on the watershed is conveyed to the estuary by runoff. Some of the deposited mercury will be retained by soils within the watershed, some will be converted to gaseous elemental mercury and re-emitted to the atmosphere, and some fraction will be conveyed into the Bay[41]. Determining how much deposited mercury is conveyed to the Bay is an extremely complex problem, requiring substantial modeling and measurement efforts. For this TMDL analysis, we will make some simplifying assumptions about the amount of mercury transmitted by different types of terrain. Although crude, the resulting estimations help put the atmospheric deposition component of stormwater runoff into perspective.

We make the reasonable assumption that developed areas (residential, industrial, and commercial) will retain less mercury than undeveloped areas (rural, agricultural, and open space). Using recent watershed land use analysis data and atmospheric deposition rates, we can estimate the amount of mercury entering each segment from indirect airborne deposition (i.e., airborne deposition coupled to runoff). The urbanized areas of the region are shown in Figure 32. For this analysis, we assume that 0.1-1% of mercury deposited onto undeveloped areas is conveyed to the Bay, whereas 10-50% of mercury falling onto developed areas is transmitted. The results are summarized in Table 20.

Bay Segment	Developed Area (m^2x10^6)	Undeveloped Area (m^2x10^6)	Global Background (low)	Global Background (high)	Urban deposition (low)	Urban Deposition (High)
A - Lower South Bay	771	1354	0.2	2.0	0.8	10.4
B - South Bay	779	1905	0.2	2.0	0.8	10.6
C - Central Bay	201	73	0.0	0.5	0.2	2.6
D - San Pablo Bay	400	1920	0.1	1.1	0.4	5.7
E - Suisun Bay	420	1106	0.1	1.1	0.4	5.7
Totals	2570	6358	0.5	7	2.6	35

Table 20: Annual mercury loadings (kg) from indirect atmospheric deposition for individual Bay segments.

4.4.d Comparison of indirect atmospheric deposition with overall watershed inputs

The watershed loadings calculated in Section 4.2 are based on transport of mercury by watershed soils into the receiving water. This implicitly incorporates indirect atmospheric deposition: watershed soil mercury concentrations are a function of watershed lithology and atmospheric deposition. The proportion of a watershed load that results from atmospheric inputs can be estimated by combining and comparing the results of Table 16 and Table 20. The maximum and minimum for watershed loading and indirect air deposition are averaged to produce best estimates. Comparison of these best estimates (Table 21) shows that in heavily urbanized watersheds (Central and South Bay), up to 25% of the watershed load may be driven by atmospheric deposition, whereas in more rural watersheds (San Pablo Bay and Suisun Bay) indirect deposition accounts for only 5-10% of the watershed loading. Although Lower South Bay has also been heavily urbanized, indirect atmospheric deposition still accounts for smaller proportion of the watershed load because the signal from contaminated sediments in the Guadalupe River drainage predominates.

Bay Segment	Best estimate of watershed load (kg/yr)	Best estimate of Indirect Air Deposition (kg/yr)	Percentage of watershed load from indirect air deposition
A - Lower South Bay	56	6	10
B - South Bay	24	6	24
C - Central Bay	4	1	25
D - San Pablo Bay	59	3	5
E - Suisun Bay	25	3	12

Table 21: Comparison of watershed loadings with indirect airborne depositional loadings for Bay segments.

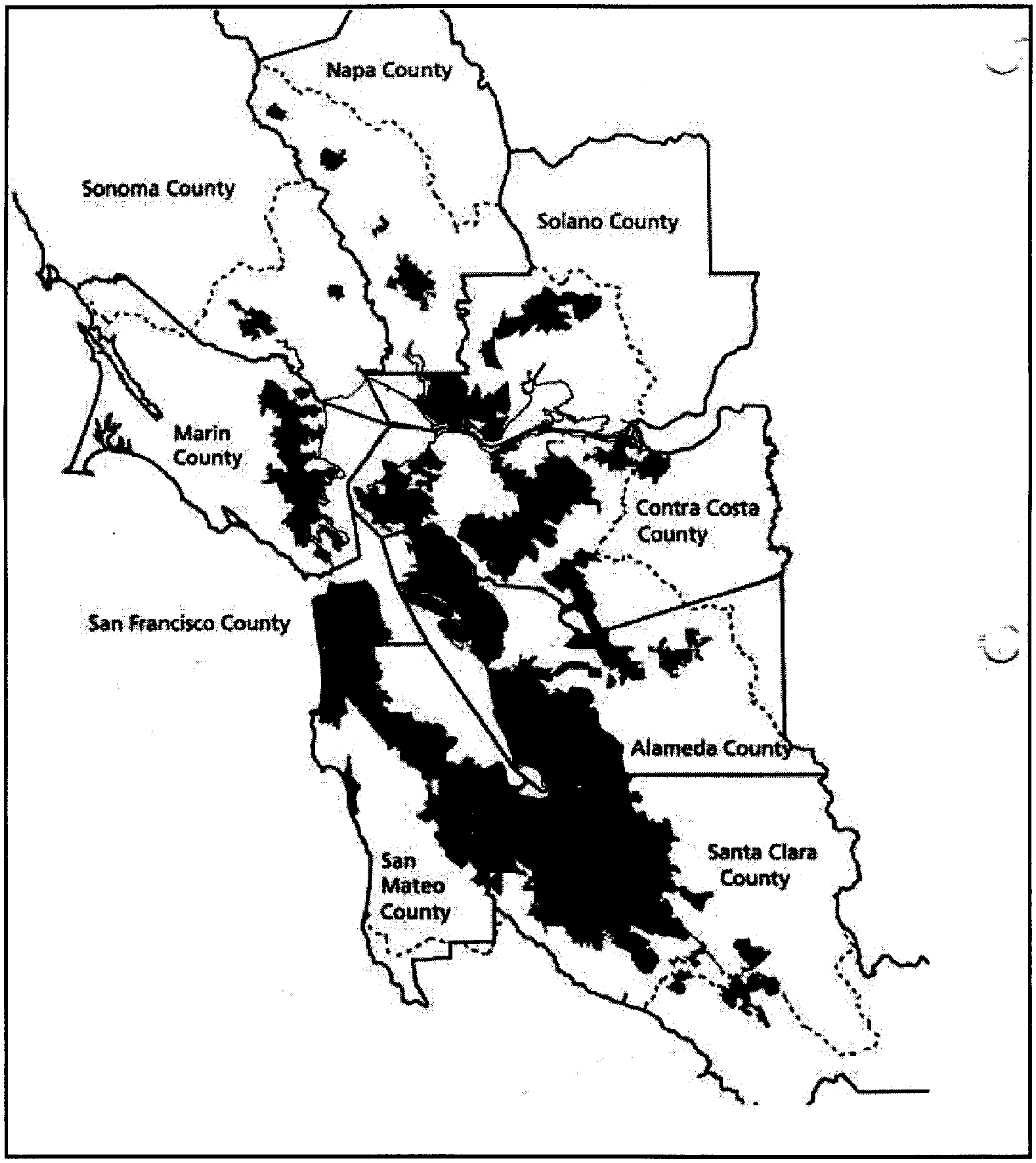


Figure 32: Location of urbanized areas within the San Francisco Bay region. Image taken from the 1995 Basin Plan. Solid lines show county boundaries, dashed line shows basin boundary.

4.5 Sediment remobilization

Mercury-laden sediment was swept into Suisun Bay and San Pablo Bay during and after the hydraulic mining era of the Gold Rush [4]. Between 1867 and 1887, approximately 115 million cubic meters of sediment was deposited in Suisun Bay, and over 250 million cubic meters of sediment was deposited in San Pablo Bay[68;69]. Following a rash of dam construction in the mid-twentieth century, the northern reach of the Bay shifted from depositional to erosional. Today, the mercury-enriched sediments buried at depth (Figure 21) are being gradually exposed, resulting in a net input of mercury from sediment remobilization.

As with other sources, we can estimate inputs from benthic remobilization based on sediment mass fluxes and the mercury concentration remobilized sediments. Historic and contemporary depth profiles indicate that over seven million cubic meters of sediment has been eroded from San Pablo Bay over thirty-three years (1951-1983) [69], while Suisun Bay lost more than 100 million cubic meters of sediment over 103 years (1887 to 1990). Converting this to mass units via Equation 7 yields 281 million kg of sediment per year eroded from San Pablo Bay, and 1.2 billion kg per year from Suisun Bay.

Those erosion rates provide first-order estimates of mercury inputs due to sediment remobilization. Sediment erosion converts bedded, buried sediments to sediments within the actively resuspended layer. So the mercury concentration of eroded sediments times the mass eroded gives the remobilization input. The mercury concentration of eroded sediments is between the contemporary value of 0.3 µg/g and the maximum concentration observed at depth, 1 µg/g. Applying these values to the erosion rates above yields a range of 84-281 kg per year in San Pablo Bay, and 386-1286 kg per year in Suisun Bay.

These are crude estimates, because they extrapolate historic erosion rates to present conditions. But they provide a useful basis for evaluating the magnitude of remobilization inputs. It is unlikely that the concentration of eroded sediments will ever be equal to the maximum concentrations observed at depth ($\approx$1µg/g at $\approx$1 meter), because the erosion rates correspond to depth changes of millimeters per year, while sediments are continuously mixed over the upper 5-20 centimeters. For this TMDL analysis, we estimate that the inputs due to remobilization of historic sediment deposits is between 100 and 400 kg per year in both Suisun Bay and San Pablo Bay.

4.6 Wastewater discharges

The mass loadings from permitted NPDES wastewater discharges are calculated from annual wastewater flow times the annual average mercury concentration. Of all sources, wastewater has the least associated uncertainty, because the flows are well known. Until recently, many of the mercury concentrations reported in the NPDES self-monitoring reports have been below the detection limit, which introduces some uncertainty. For this TMDL report, where we don't have good analytical data, we make reasonable estimates based on the detection limits and the known performance of secondary and advanced wastewater treatment plants. As of January, 2000, we have required all NPDES wastewater dischargers in our region to use analytical techniques with detection limits low enough to accurately measure mercury in wastewater.

The locations of municipal wastewater discharges are shown in Figure 33, and their mercury loads are shown in Table 22. The locations of industrial wastewater discharges are shown in Figure 34, and their mercury loads are shown in Table 23.

Some of the uncertainty in the estimates comes from the need for better analytical data, which is currently being addressed through the NPDES self monitoring program. Much of the uncertainty, however, is simply a mathematical reality that results from propagation of error while summing over fifty terms. For example, we performed a sensitivity analysis on the POTW calculations. We substituted 0.030 µg/L and 0.020 µg/L for the maximum and minimum annual average concentration for each POTW that had a large or medium information gap. That range is a reasonable projection of year-to - year variability for plant performance. The resulting load estimate for POTWs was 16-24 kg per year, compared to our current estimate of 15-45 kg per year (Table 22).

There are two industrial facilities (USS POSCO and CH&H Sugar) that have estimated loads that appear to be tenfold greater than other industrial dischargers. Preliminary results from USS POSCO using better analytical data indicate that their mercury load is tenfold lower than the estimate in Table 22, and we expect the same to be true for C&H Sugar. Once they new analytical results are submitted, the maximum and minimum estimates for industrial loads will likely be reduced by 8-10 kg per year.

In summary, our best estimates using available data are that industrial and municipal wastewater discharges contribute 25-62 kg per year. Now that NPDES permitees are all using the best possible analytical techniques, we expect that this estimate will be refined to 15 – 40 kg per year.

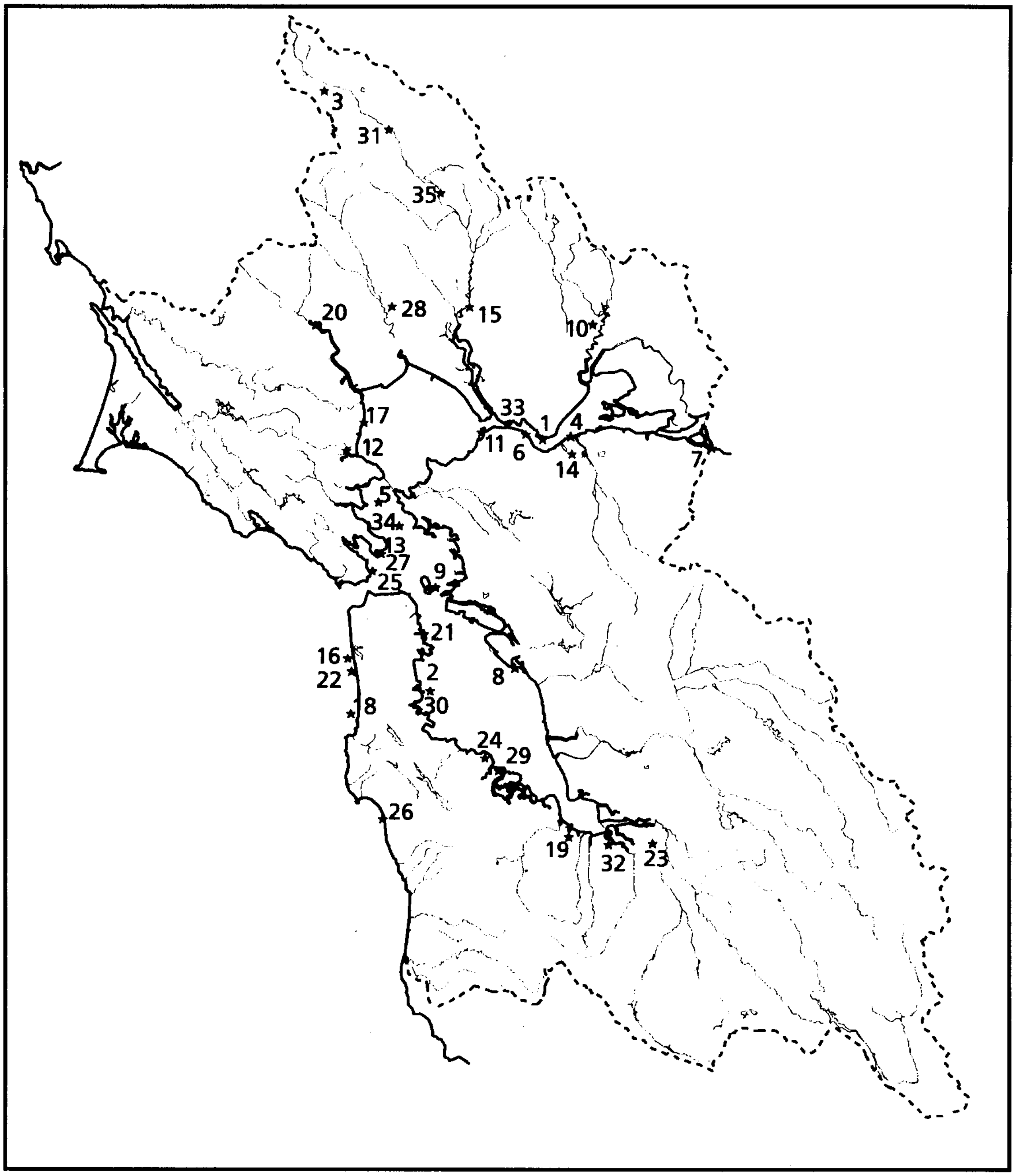


Figure 33: Locations of municipal wastewater discharges in the San Francisco Bay Region. Image taken from the 1995 Basin Plan.

Facility	Bay Segment	Map Key	Annual mercury load (kg), min	Annual mercury load (kg), max	Best Estimate of annual flow (MGD)	Best Estimate of annual average mercury conc. (µg/L) - min	Best Estimate of annual average mercury conc. (µg/L) - max	Information Gap
San Jose/Santa Clara WPCP	A	23	0.6	1.0	120.1	0.003	0.005	Small
City of Palo Alto	A	19	0.1	0.4	25.7	0.003	0.010	Smalll
City of Sunnyvale	A	32	0.1	0.1	14.6	0.004	0.006	Small
EBDA, East Bay Dischargers Authority	B	8	3.1	4.6	76.75	0.024	0.036	Medium
City & Co. of S.F., Southeast	B	21	1.2	3.7	75	0.010	0.030	Medium
So. Bayside System Authority	B	29	0.6	0.9	20.7	0.017	0.025	Small
City of San Mateo	B	24	0.6	0.9	13.1	0.028	0.042	Small
LAVWNMA, Livermore-Amador Valley WMA	B	8	0.2	3.7	11	0.010	0.200	Large
So. S.F./ San Bruno WQCP	B	30	0.7	1.0	10.2	0.040	0.060	Small
City of Burlingame	B	2	0.7	1.0	4.09	0.096	0.144	Small
City of Millbrae	B	2	0.3	0.5	1.9	0.104	0.156	Medium
City & Co. of S.F., Int. Airport	B	2	0.1	0.2	0.86	0.096	0.144	Small
East Bay MUD	C	9	1.6	2.5	77.3	0.013	0.019	Small
West County Agency	C	34	0.3	5.5	16.5	0.010	0.200	Large
Central Marin Sanitation A.G.	C	5	0.3	0.4	10.94	0.016	0.024	Small
West County Wastewater Dist.	C	34	0.1	2.2	6.7	0.010	0.200	Large
Sewerage Agency of So. Marin	C	27	0.1	1.0	3.14	0.010	0.200	Medium
Sausalito-Marin City S.D.	C	25	0.0	0.5	1.36	0.010	0.200	Large
Marin Co. S.D. #5	C	13	0.0	0.3	0.78	0.010	0.200	Large

Table 22: (part 1 of 2) Best estimates of current annual mercury loads from individual POTWs. Where possible, flow and concentration data are taken from 1999 annual NPDES reports. Minimum and maximum concentrations are calculated as 80% and 120% of the 1999 annual average concentration. Where flow data are not available from 1999 NPDES reports, Basin Plan flows are used. Where annual average concentrations are non-detect or not available, reasonable assumptions about the minimum and maximum concentrations are made (e.g, annual averages are less than permit limits or the detection limit, whichever is lower). Large data gaps indicate 1999 annual reports not reviewed yet. Medium data gaps indicate the need for better mercury measurements. Small data gaps indicate flows taken from 1999 NPDES annual reports and mercury concentrations measured using adequately low detection limits. Table continues on next page.

Facility	Bay Segment	Map Key	Annual mercury load (kg), min	Annual mercury load (kg), max	Best Estimate of annual flow (MGD)	Best Estimate of annual average mercury conc. (µg/L) - min	Best Estimate of annual average mercury conc. (µg/L) - max	Information Gap
Napa S.D.	D	15	0.2	1.2	14.2	0.010	0.050	Large
Vallejo Sanitation & Flood Cont.	D	33	0.2	4.2	12.5	0.010	0.200	Large
City of Petaluma	D	20	0.3	0.5	10.12	0.019	0.029	Small
Novato S.D.	D	17	0.1	0.2	6.11	0.014	0.022	Small
Sonoma Valley County S.D.	D	28	0.0	0.2	2.8	0.010	0.050	Large
City of Pinole	D	11	0.0	0.8	2.32	0.010	0.200	Large
Las Gallinas Valley S.D.	D	12	0.0	0.1	1.7	0.010	0.050	Large
Rodeo S.D.	D	11	0.0	0.0	0.74	0.004	0.006	Small
City of Calistoga	D	3	0.0	0.0	0.6	0.010	0.050	Large
City of Hercules	D	11	0.0	0.1	0.37	0.010	0.200	Large
Town of Yountville	D	35	0.0	0.0	0.36	0.010	0.050	Large
City of St. Helena	D	31	0.0	0.0	0.34	0.010	0.050	Large
Central Contra Costa S.D	E	4	2.5	3.8	45.8	0.033	0.050	Medium
Delta Diablo S.D.	E	7	0.2	1.1	13.6	0.010	0.050	Large
Fairfield Suisun Sewer Dist.	E	10	0.2	1.1	12.8	0.010	0.050	Large
City of Benecia	E	1	0.0	0.8	2.3	0.010	0.200	Large
Mountain View S.D.	E	14	0.0	0.1	1.47	0.010	0.050	Large
Contra Costa Co. S.D. No. 5	E	6	0.0	0.0	0.01	0.010	0.200	Large
Totals			14.8	44.6	619			

Table 9 (part 2 of 2, continued from previous page) Best estimates of current annual mercury loads from individual POTWs. Where possible, flow and concentration data are taken from 1999 annual NPDES reports. Minimum and maximum concentrations are calculated as 80% and 120% of the 1999 annual average concentration. Where flow data are not available from 1999 NPDES reports, Basin Plan flows are used. Where annual average concentrations are non-detect or not available, reasonable assumptions about the minimum and maximum concentrations are made (e.g, annual averages are less than permit limits or the detection limit, whichever is lower). Large data gaps indicate 1999 annual reports not reviewed yet. Medium data gaps indicate the need for better mercury measurements. Small data gaps indicate flows taken from 1999 NPDES annual reports and mercury concentrations measured using adequately low detection limits.

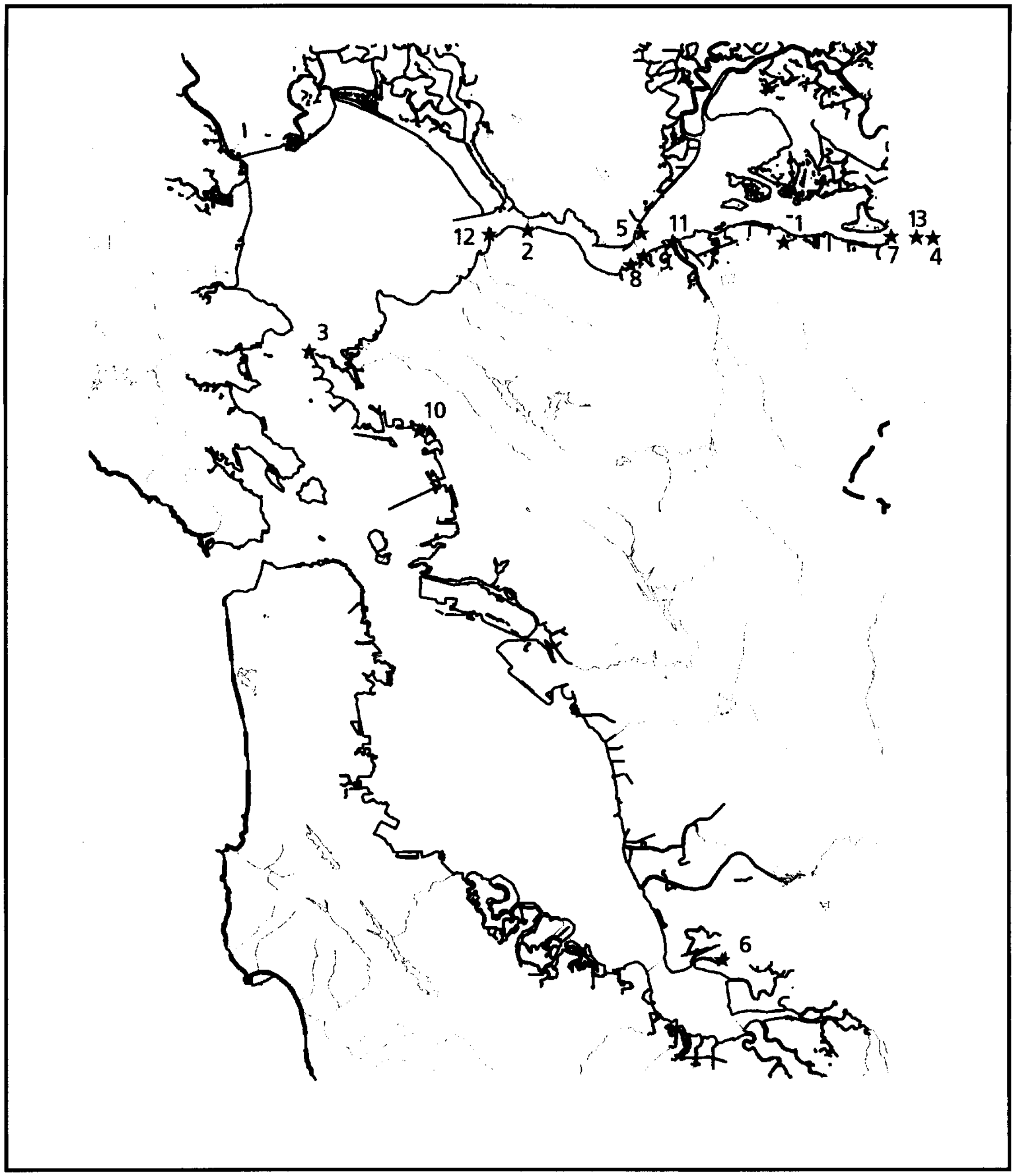


Figure 34: Locations of industrial wastewater discharges in the San Francisco Bay Region. Image taken from the 1995 Basin Plan.

Facility	Bay Segment	Map Key	Annual mercury load (kg), min	Annual mercury load (kg), max	Best Estimate of annual flow (MGD)	Best Estimate of annual average mercury conc. (µg/L) - min	Best Estimate of annual average mercury conc. (µg/L) - max	Information Gap
FMC Newark	A	6	NA	NA	NA	0.05	0.2	Large
PG&E Portrero Power Plant	B		0.03	0.1	202.0	0.0001	0.0002	Large
San Francisco Int. Airport	B		0.02	0.0	0.9	0.016	0.024	Medium
Zeneca Agricultural Products	C	10	NA	NA	NA	0.05	0.2	Large
C&H Sugar Co.	D	2	5.2	7.8	24.5	0.128	0.192	Medium
Chevron U.S.A.	D	3	0.5	1.2	6.0	0.05	0.12	Large
Tosco Corp. Rodeo Refinery	D		0.1	0.2	1.6	0.04	0.06	Medium
Rhone Poulenc Basic Chemical Co.	E	9	NA	NA	NA	0.05	0.2	Large
USS Posco	E	13	4.0	6.0	9.1	0.26	0.40	Medium
Tosco Corp. Avon Refinery	E	11	0.2	0.3	4.3	0.032	0.048	Medium
Equilon Enterprises LLC.	E	8	0.2	0.3	5.3	0.024	0.036	Medium
Dow Chemical Co.	E	4	0.2	0.7	2.2	0.05	0.2	Large
Exxon	E	5	0.2	0.3	1.9	0.05	0.1	Large
General Chemical Corp. Bay Point Works	E	1	0.0	0.1	0.3	0.05	0.2	Large
GWF Power System, East Third Street Power Plant	E		0.006	0.026	0.1	0.05	0.2	Large
GWF Power System, Nichols Road Power Plant	E		0.004	0.016	0.0	0.05	0.2	Large
Totals			11	17	258			

Table 23: Best estimates of current annual mercury loads from individual major industrial facilities. Where possible, flow and concentration data are taken from 1999 annual NPDES reports. Minimum and maximum concentrations are calculated as 80% and 120% of the 1999 annual average concentration. Where flow data are not available from 1999 NPDES reports, Basin Plan flows are used. Where annual average concentrations are non-detect or not available, reasonable assumptions about the minimum and maximum concentrations are made (e.g, annual averages are less than permit limits or the detection limit, whichever is lower). Large data gaps indicate 1999 annual reports not reviewed yet. Medium data gaps indicate the need for better mercury measurements. Small data gaps indicate flows taken from 1999 NPDES annual reports and mercury concentrations measured using adequately low detection limits. NA indicates data not available at the time this draft was submitted.

4.7 Summary of mercury sources

The load calculations for all of San Francisco Bay are concisely summarized in Figure 35. Loads for individual segments are tabulated in Table 24-Table 28, and summed up in Table 29.

The largest loadings are inputs from the Central Valley and remobilization of contaminated sediments. These are essentially background processes, in that they are predominantly controlled by climate, freshwater inflow, and sediment dynamics. The Central Valley Regional Board is assessing mercury sources within its region and investigating the links between Central Valley sources and methylmercury production within San Francisco Bay. However, remedial actions on mines within the Central Valley probably won't change the overall sediment budget or the average mercury composition in sediments, so the total mercury load from the Central Valley will not likely change.

The load calculations for controllable sources within the San Francisco Bay region are summarized in Figure 36. The largest mercury load comes from watershed sources, amounting to ≈170 kg per year. A substantial portion of watershed loadings may be controllable. For example, stopping the inflow of contaminated sediments through the Guadalupe River could reduce watershed loadings by 40-50 kg per year. Watershed loadings also include indirect atmospheric deposition, which amounts to 5-25% of watershed loadings. So reduction of regional air deposition rates down to global background levels could reduce another 4-20 kg per year from watershed loadings, as well as 3-6 kg per year from direct deposition onto the Bay.

These other watershed loadings help put the impacts of wastewater discharges into perspective. Over the past three decades, we have invested over two billion dollars in wastewater treatment technology, and reduced mercury loads in wastewater by 90% or more. Yet, we still have mercury contamination in sediments, and in places we still see dissolved methylmercury concentrations over the dissolved methylmercury target (0.05 ng/L). Why? We have not addressed all possible sources of mercury, but rather have focused our attention on wastewater sources. A properly crafted watershed plan has to address all sources within the watershed.

It is important to recognize that focusing on total mercury loadings alone is not sufficient to protect beneficial uses. The form of mercury that bioaccumulates is methylmercury. So all of our control measures, including load reductions, wetlands creation and management, and disposal of dredged material, have to be directed at the methylmercury target. This is explained in detail in the next section (Linkage Analysis). With a clear understanding of the linkages between mercury sources and mercury bioaccumulation, we can establish a rational basis for setting load and wasteload allocations.

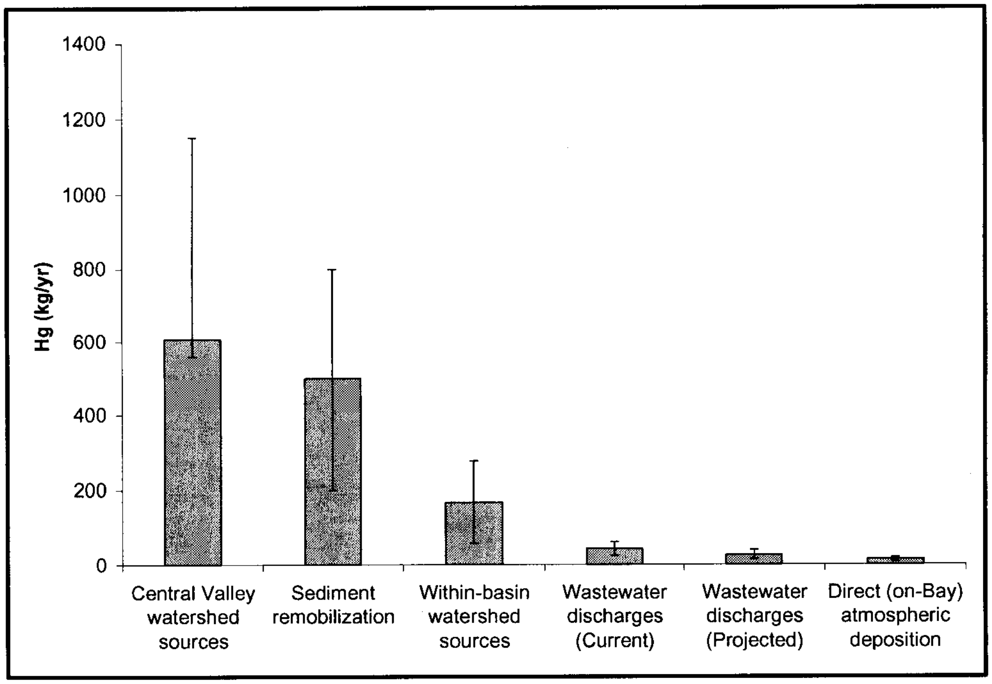


Figure 35: Summary of all annual mercury loads to all of San Francisco Bay. Current wastewater loads reflect our best current estimates. Projected wastewater estimates reflects estimates based on preliminary results of low-level wastewater analyses implemented in January, 2000.

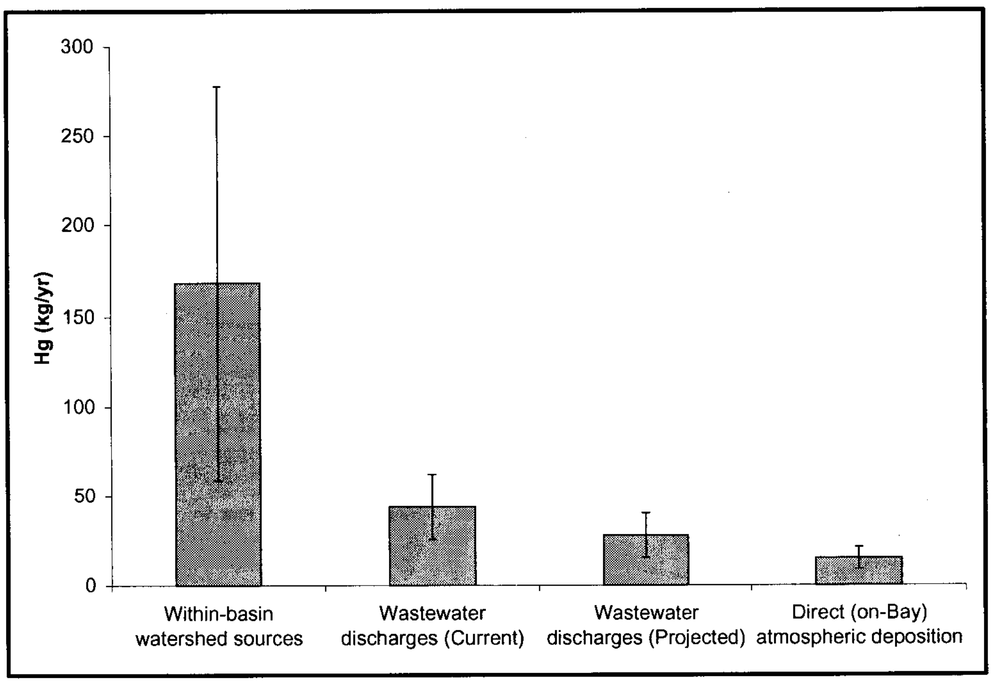


Figure 36: Summary of controllable mercury loads to all of San Francisco Bay.

	Best Estimate (kg/yr)	Maximum (kg/yr)	Minimum (kg/yr)
Central Valley watershed sources	6	12	6
Within-basin watershed sources	56	99	14
Direct (on-Bay) atmospheric deposition	0.7	1.1	0.4
Sediment remobilization	NA	NA	NA
Wastewater discharges	1.2	1.5	0.9
Total	64	113	21

Table 24: Mercury load summary for Segment A (Lower South Bay).

	Best Estimate (kg/yr)	Maximum (kg/yr)	Minimum (kg/yr)
Central Valley watershed sources	61	115	56
Within-basin watershed sources	24	38	10
Direct (on-Bay) atmospheric deposition	3	4	2
Sediment remobilization	NA	NA	NA
Wastewater discharges	12.0	16.5	7.5
Total	100	174	75

Table 25: Mercury load summary for Segment B (South Bay)

	Best Estimate (kg/yr)	Maximum (kg/yr)	Minimum (kg/yr)
Central Valley watershed sources	607	1150	558
Within-basin watershed sources	4	6	2
Direct (on-Bay) atmospheric deposition	3	5	2
Sediment remobilization	NA	NA	NA
Wastewater discharges	7.4	12.4	2.4
Total	622	1173	564

Table 26: Mercury load summary for Segment C (Central Bay)

	Best Estimate (kg/yr)	Maximum (kg/yr)	Minimum (kg/yr)
Central Valley watershed sources	607	1150	558
Within-basin watershed sources	59	94	24
Direct (on-Bay) atmospheric deposition	6	8	3
Sediment remobilization	250	400	100
Wastewater discharges	12	17	6.9
Total	933	1669	691

Table 27: Mercury load summary for segment D (San Pablo Bay)

	Best Estimate (kg/yr)	Maximum (kg/yr)	Minimum (kg/yr)
Central Valley watershed sources	607	1150	558
Within-basin watershed sources	25	40	10
Direct (on-Bay) atmospheric deposition	2	3	1
Sediment remobilization	250	400	100
Wastewater discharges	11	14.7	7.8
Total	895	1608	677

Table 28: Mercury load summary for segment E (Suisun Bay)

	Best Estimate (kg/yr)	Maximum (kg/yr)	Minimum (kg/yr)
Central Valley watershed sources	607	1150	558
Within-basin watershed sources	168	278	58
Direct (on-Bay) atmospheric deposition	15	21	9
Sediment remobilization	500	800	200
Wastewater discharges	44	62	25
Total	1333	2310	850

Table 29: Mercury load summary for all segments of San Francisco Bay

5. Linkage Analysis

5.1 Links between sources, numeric targets and beneficial uses

The linkage analysis defines the connection between numeric targets and identified sources. The linkage is defined as the cause-and-effect relationship between the selected indicators, the associated numeric targets, and the identified sources (Figure 37). It provides the basis for estimating total assimilative capacity and any needed load reductions.

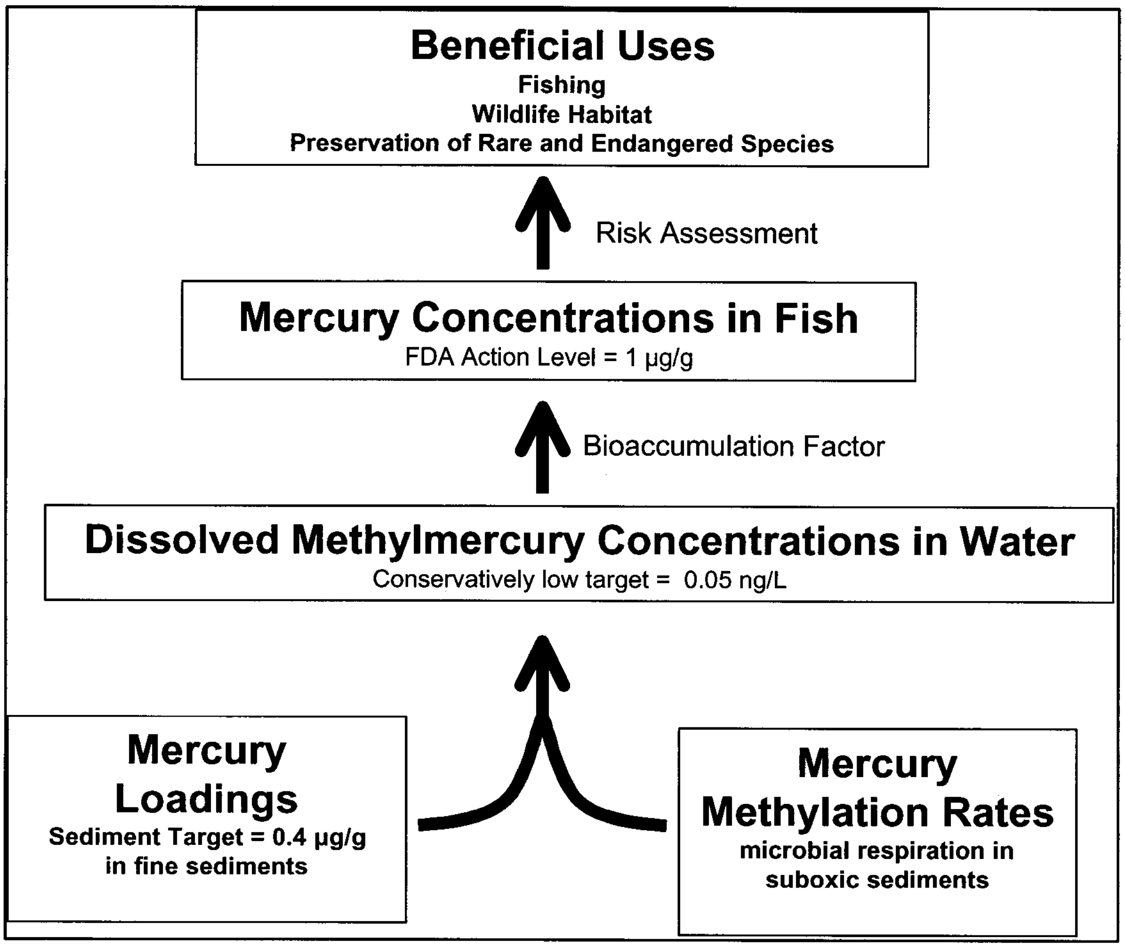


Figure 37: Relationship between beneficial uses and numeric targets established for the mercury TMDL.

The beneficial uses most threatened by mercury pollution are sport fishing, wildlife habitat, and preservation of rare and endangered species. Risk assessment established the link between beneficial uses and the indicator, fish tissue mercury concentrations. A safe level of mercury in fish is currently a matter of national debate. At present, the most defensible indicator for protection of human health is the FDA action level of 1 μg/g. The fish tissue indicator is related to dissolved methylmercury concentrations by the bioaccumulation factor (BAF), according to Equation 4 (see Numeric Targets, Section 3.6). At present, the best BAF available comes from the U.S. EPA Mercury Study Report to Congress[41], which reports a BAF of 10^7 for dissolved methylmercury. Although that BAF is derived for freshwater ecosystems, and we do need to establish a BAF specific to San Francisco Bay, there is good evidence that the 10^7 is a reasonable BAF for the Bay.

Preliminary results (Table 13, Section 3.6) show that the baywide average dissolved methylmercury concentration is 0.03 ng/L. The baywide average fish tissue mercury concentration from the 1994 and 1997 RMP studies[15] is 0.3μg/g. The resulting BAF, calculated according to Equation 3, is 10^7. This BAF may not be appropriate to the highest trophic levels, such as leopard sharks, but it is a good starting point for quantifying mercury bioaccumulation. Applying this bioaccumulation factor to the FDA action level of 1 μg/g yields a methylmercury target of 0.1 ng/L. We have selected a lower target, 0.05 ng/L, to address wildlife protection and to provide an implicit margin of safety.

The methylmercury target establishes a link between a measurable water quality parameter and beneficial uses. There are two interacting processes that control methylmercury concentrations: mercury loadings, and mercury methylation rates. We need better information on where and how mercury is methylated and demethylated in the Bay, so the best we can do at present is to ask "where do we have ongoing mercury pollution," and "where is that associated with increased dissolved methylmercury." Our sediment target, 0.4 μg/g in sediments, normalized to percent fines, helps identify ongoing mercury pollution. Our assessment of dissolved methylmercury helps link pollution to fish contamination through bioaccumulation.

Section 5.1 Key Points:

- The Linkage Analysis defines the connection between numeric targets and identified sources.
- There are two targets for this TMDL: dissolved methylmercury in water, and total mercury in fine sediments.
- The sediment target identifies ongoing pollution
- The methylmercury target links pollution to fish contamination

5.2 The mercury cycle

How does mercury get into fish? The link to fish is through methylmercury. Methylmercury has a high affinity for sulfur-containing proteins. In the environment, tissue concentrations of mercury increase every time you move up a step in the food chain because consumers tend to retain protein preferentially over other components. Predators magnify the protein concentration in their prey by "eating the grapes and spitting the skins." [70]

How is methylmercury formed in the environment? Sulfate-reducing bacteria convert inorganic mercury to methylmecury as a by-product of their normal respiration [71]. To methylate mercury, the bacteria first have to take it up across their cell membranes. This requires mercury to be in a form than can cross the membrane. Dissolved, neutrally charged complexes of mercury cross cell membranes most readily[72]. Dissolved, neutral complexes of inorganic mercury (Hg^{2+}) and sulfide (S^{2-}) have been implicated as important links to methylmercury production.

The involvement of sulfate reducing bacteria and the role of sulfide complexes explains why mercury methylation rates are highest in wetlands, marshes, and suboxic sediments [30;67;73;74]. The importance of neutrally charged complexes also means that methylation rates tend to be highest in brackish environments. Activity of sulfate reducing bacteria increases with increasing salinity because of the increased supply of sulfate. Methylation rates also increase with increasing salinity, to a point, but at higher salinities, formation of charged mercury complexes tends to decrease mercury uptake by bacteria. Many other physical factors also affect mercury methylation rates, including temperature, pH, organic carbon, and sunlight [75;76].

The concentration of dissolved methylmercury in ambient waters depends on the *net* methylation rate, that is, the balance between methylation rates and demethylation rates. Demethylation can occur through photo-ablation (destruction by light) and by bacterial respiration. Bacteria demethylate methylmercury as either a detoxificaction mechanism (mer-degradation) or a source of carbon (oxidative demethylation). In the former pathway, elemental mercury (Hg^0) is produced, in the latter, the end product is Hg^{2+}. It is important to understand the microbial demethylation pathway in order to assess mercury fate and transport. The mer-degradation pathway provides a gaseous escape for Hg^0, while oxidative demethylation results in Hg2+, which remains in the waterbody and can be converted back to methylmercury.

In the absence of specific, mechanistic information, net methylmercury production rates can be estimated from methylmercury concentrations. The ratio of methylmercury to total mercury is a useful indicator of ecosystems with high methlyation efficiencies. In watersheds across the United States, methylmercury to total mercury ratios higher than 5% are associated with enhanced mercury bioaccumulation at the highest trophic levels [30].

How susceptible are mercury sources in San Francisco Bay to methylation? The susceptibility to methylation, or *bioavailability*, depends on the chemical form of mercury in the source and the biogeochemistry of the receiving water. We know that neutral complexes of dissolved inorganic mercury are the link to methylating bacteria, so sources of dissolved mercury may be more readily methylated than particulate sources. However, mercury can desorb from particles, enhancing its availability, and dissolved mercury can be complexed by organic ligands or form charged complexes, decreasing its bioavailability (Figure 38).

In the first phase of this TMDL, we will investigate the bioavailability in all sources, to help develop a rigorous numeric model for mercury bioaccumulation. Such a model has been developed and tested for freshwater lakes [77-79], and used to calculate assimilative capacities. There is no such model available for the more complex processes in estuarine systems, so we have to set priorities for load reductions based on a weight of evidence approach.

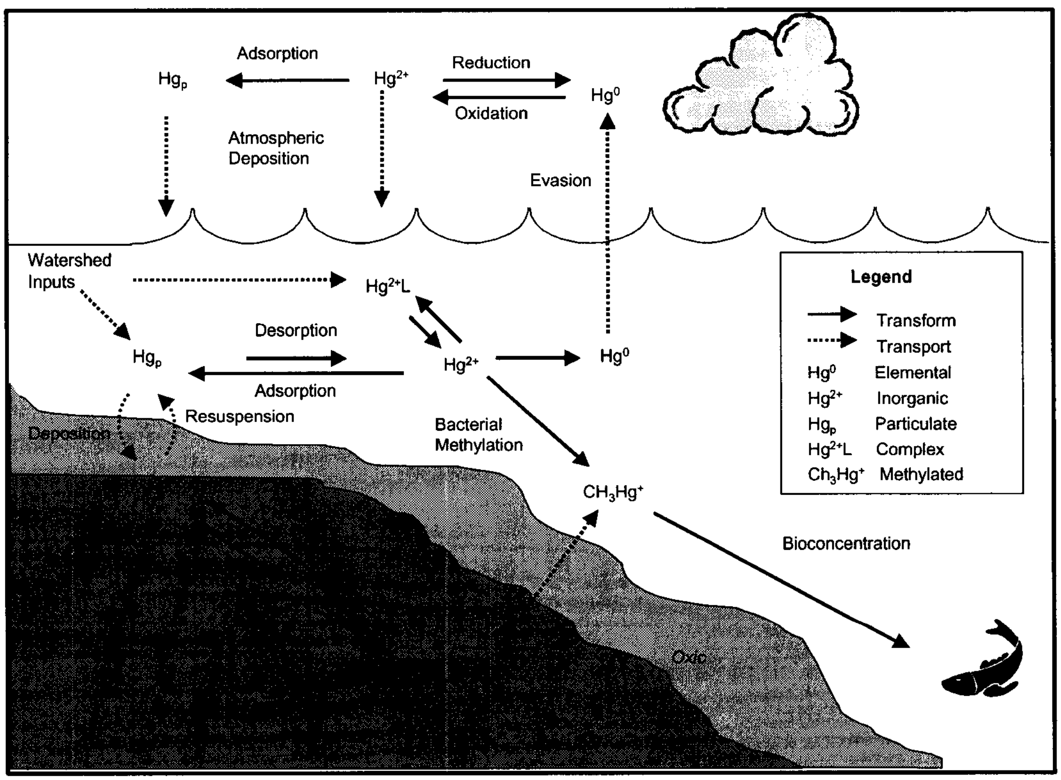


Figure 38: The complex biogeochemical cycling of mercury.

Section 5.2 Key Points:

- Mercury in the environment is linked to mercury in fish via methylmercury
- Methylmercury is produced by sulfate-reducing bacteria in sub-oxic environments
- Mercury methylation is highest in wetlands, marshes, and mudflats
- Ambient methylmercury concentrations depend on net methylation rates
- Conversion of mercury to methylmercury depends on both the bioavailability of the source and the biogeochemistry of the receiving water
- In the absence of a numeric model predicting methylmercury responses to proposed control measures, we use a weight of evidence approach to link proposed load reductions to meeting the methylmercury target.

5.3 Weight of evidence linking identified sources to targets

We use the weight of evidence approach to evaluate the condition of the Bay and link proposed source reductions to numeric targets. We start by assessing the condition of the Bay with respect to the methylmercury target. Then we describe the condition of the Bay with respect to the sediment target. Finally, we describe the spatial associations between exceedance of the sediment target and exceedance of the methylmercury target. The spatial association between ongoing pollution identified by the sediment target and bioaccumulation identified by the methylmercury target establishes the connection between proposed source control measures and mercury levels in fish.

Overall, the Bay is below the numeric target for methylmercury, as are individual segments (Table 30). Given that information, one implementation option might be to delist all segments of the Bay except for Lower South Bay. This is a valid outcome of a TMDL analysis, especially when a waterbody has been listed as a precautionary measure. However, we would need more data on dissolved methylmercury concentrations, particularly from the shallows and margins, before even considering that path. Furthermore, mercury management requires a holistic, watershed approach, and participation by all stakeholders within the watershed. Even though the worst impairment appears to be constrained to the southern extremity of the Bay, we will propose mass limits for sources in all segments as well as requiring reductions from air sources within the region to guard against exceedance of the numeric targets in the future, and to ensure participation from the entire region.

Segment	A	B	C	D	E
Name	Lower South Bay	South Bay	Central Bay	San Pablo Bay	Suisun Bay
Median methylmercury concentration (ng/L)	0.01	0.01	0.02	0.02	0.02
Average methylmercury concentration (ng/L)	0.04	0.02	0.02	0.02	0.03
Number of samples	3	6	6	4	7

Table 30: Evaluation of the dissolved methylmercuy target in Bay segments. The dissolved methylmercury target is 0.05 ng/L.

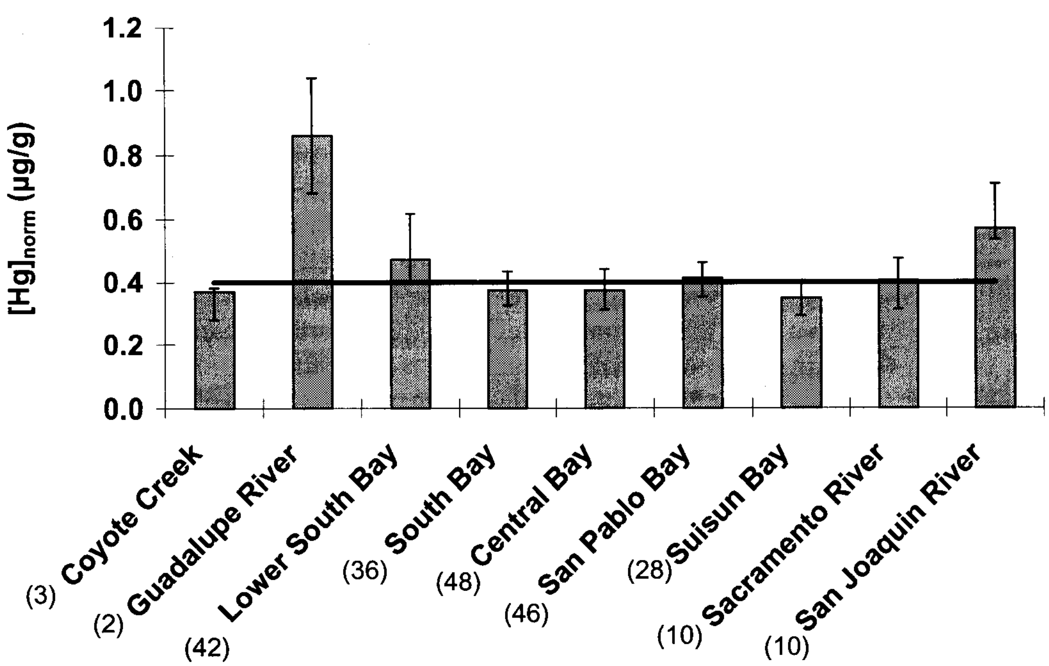


Figure 39: Evaluation of the sediment target in San Francisco Bay waterbodies and conveyances. The solid grey bars indicate the median values for $[Hg]_{norm}$; the error bars indicate the 75'th and 25'th percentiles; the numbers in parentheses indicate the number of measurements in each waterbody of conveyance. The solid black horizontal line shows the TMDL target ($[Hg]_{norm}$ = 0.40 µg/g).

The sediment target is significantly exceeded in one segment of the Bay: Lower South Bay. The highest dissolved methylmercury concentration (0.11 ng/L) measured anywhere in the Bay by the RMP is found in that segment, in Guadalupe Slough (Table 13, Section 3.6). Exceedance of the sediment target is driven by ongoing loads of mercury-laden sediment from the Guadalupe River watershed (Section 4.3.b). Mercury from that source is susceptible to methylation, leading to elevated methylmercury concentrations in Lower South Bay sediment and water.

Although we need a more rigorous numeric model to quantify factors affecting methylmercury in the Bay, the weight of evidence clearly identifies our highest priorities. The highest concentration of dissolved methylmercury observed anywhere in the Bay is is spatially associated with ongoing inputs from the Guadalupe River watershed, which drains the New Almaden mining district. Therefore, we will calculate an assimilative capacity for Lower South Bay using current sediment concentrations and the sediment target (Section 5.5), and allocate loads within that segment based on attainment of the sediment target.

The sediment target in San Pablo Bay is not exceeded by a significant amount. Preliminary results show that the dissolved methylmercury target is attained in that segment. Therefore, in San Pablo Bay, and all other Bay segments attaining the sediment target (South Bay, Central Bay, Suisun Bay) load allocations must be based on precautionary measures and performance standards, rather than the assimilative capacity.

The San Joaquin River, a conveyance at the boundary between the Central Valley and San Francisco Bay Regions, significantly exceeds the sediment target. However, the links to specific sources are not clearly defined, as they are with the Guadalupe River. The San Joaquin River also exceeded the dissolved methylmercury target one of the two times measured. We consider this to be a potential threat to the beneficial uses of the estuary. Therefore, we will partner with the Central Valley Regional Board to determine the mercury sources that cause exceedance of the mercury target in the San Joaquin River conveyance. The Central Valley Regional Board has already undertaken a study to determine sources of bioavailable mercury to our region. We will look to that study to guide source control measures in the Central Valley Region.

We also seek to reduce regional mercury releases into the atmosphere. Although we do not have clear linkages between atmospheric emissions in this region and dissolved methylmercury concentrations in water, there is ample evidence from other regions of the United States that are not impacted by legacy mines showing that atmospheric mercury sources are extremely bioavailable [80-83]. Our analysis shows that up to 25% of mercury loads in urbanized watershed can result from atmospheric deposition (Section 4.4.c), so reduction of regional emissions to the atmosphere is linked to protection of beneficial uses.

This is a phased TMDL approach. In the first phase, we act to reduce loads from Lower South Bay, the segment with the most obvious and evidence for impairment. At the same time, we will continue to develop information and investigate links between mercury sources and bioaccumulation in all Bay segments. We are proposing mass limits for all segments as a precaution against future impairment, so we will be reasonable in our derivation of wasteload allocations. The wasteload allocations derived for segments north of the Dumbarton Bridge should, above all, ensure attainment of standards, but they should also reflect the fact that they are precautionary limits.

5.4 Box Model Approach to Assimilative Capacity Calculations

The assimilative capacity is the maximum loading rate (in kg per year) that the waterbody can receive and attain the target within a reasonable amount of time. A simple box model approach can be used to calculate the assimilative capacity and evaluate the time to attain the target. In the box model approach, the Bay is divided into appropriate segments based on known physical and biogeochemical processes. Each segment is treated as a box with three main components: the *reservoir*, *inputs* to the reservoir, and *outputs* from the reservoir (Figure 40).

The reservoir of mercury also has an associated residence time (τ), which expresses the length of time (in years) it takes to replace the entire reservoir. The residence time is dependent on the size of the reservoir, the input rates, and the output rates. In general, as a reservoir gets bigger, its residence time increases. As input and output rates increase, residence time decreases. Residence time is the factor that determines time to attaining the target for any given control strategy.

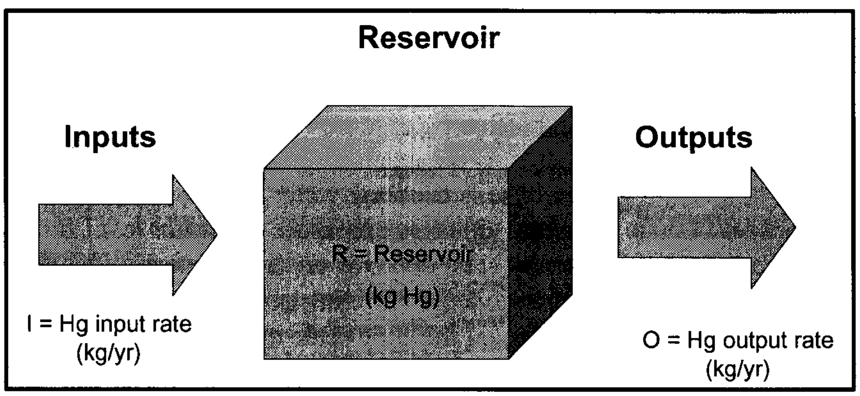


Figure 40: Generalized diagram of a box model calculation.

Input rates relative to output rates determine how the reservoir increases or decreases with time. If inputs are greater than outputs, than the reservoir will be constantly increasing. If inputs are less than outputs, the reservoir will be constantly decreasing. If inputs balance outputs, than the reservoir is at *steady state*, i.e. its size will remain constant over time.

Under steady state conditions, the residence time can be computed from the size of the reservoir and either the input rate or the output rate (Equation 8). By analogy, consider the reservoir to be water in bathtub, where water is draining out of the tub at the same rate that it is flowing in. The residence time is simply the volume of water in the tub (liters) divided by the flow rate in or out (liters per unit time). In other words, it is the time it would take to fill the tub exactly once if the tub started off empty.

Equation 8

$$\tau \text{ (yr)} = R_{Hg} \text{ (kg)} / I \text{ (kg/yr)} = R_{Hg} \text{ (kg)} / O \text{ (kg/yr)}$$

The concept of residence time is fundamental to many problems of contaminant fate and transport. Residence time can be expressed for many properties. Hydraulic residence time refers to the length of time to replace water in an entire waterbody exactly once. Sediment residence time refers to the amount of time to replace all of the active sediments in a waterbody. Contaminant residence time is the time to replace the entire mass of that contaminant in a waterbody. Residence times calculated under the steady state assumption always refer to the input or removal rate used to calculate τ, i.e. "residence time with respect to all inputs" or "residence time with respect to removal."

Residence time is a useful way of comparing the rates of important processes. For example, the residence time of methylmercury with respect to removal by demethylation is days at most. The residence time for water is 1-60 days in the northern reach, and 120-160 days or more in the South Bay, depending on rainfall. Therefore, under most conditions, production and loss of methylmercury within the Bay are likely more important processes controlling methylmecury concentrations than actual inputs of methylmercury.

In nature, the steady state condition can often be assumed when input and output rates are small relative to the reservoir size. That is, if the reservoir is a swimming pool instead of a bathtub, it doesn't matter if a garden hose is trickling water in twice as fast as a drain is trickling it out. We won't notice a change unless we measure the water level for a very long time. Thus, the assumption of steady state depends on the time scale: for all practical purposes, the water level in the aforementioned swimming pool is at steady state on the time scale of hours, but may be increasing on the time scale of days or weeks.

These simple concepts can be applied to the problem of mercury fate in the Bay. Using the target concentration for mercury in sediments, and the best available estimates of input rates, output rates, and reservoir size, the resulting assimilative capacity can be evaluated.

5.5 Assimilative capacity to meet sediment target in Lower South Bay

We determine the assimilative capacity for Lower South Bay by comparing the current reservoir of mercury to the target reservoir (Figure 41). The mercury reservoir in a segment is the total mass of mercury in the resuspendable sediments (the *active sediments*) of that segment. The current reservoir (Rc) is calculated as the total mass of active sediments times the current concentration of mercury in those sediments (Equation 9). The target reservoir (R_t) is calculated as the total mass of active sediments times the target concentration of mercury in those sediments Equation 10. Current and target mercury concentrations are normalized to percent fines, so we multiply the normalized concentrations by percent fines to get mercury reservoir masses.

Equation 9

$$R_c\,(kg) = \frac{[Hg]_{norm}\,(\mu g)}{1\;\;(g)} \times F_{63} \times \frac{M_{sed}\,(kg)}{1} \times \frac{1000\,g}{kg} \times \frac{1\,kg}{10^9\,\mu g}$$

Equation 10

$$R_t\,(kg) = \frac{0.4\;\;(\mu g)}{1\;\;(g)} \times F_{63} \times \frac{M_{sed}\,(kg)}{1} \times \frac{1000\,g}{kg} \times \frac{1\,kg}{10^9\,\mu g}$$

Where:
F_{63} = percent fines (<63 µm), expressed as a fraction
M_{sed} = mass of active sediment
$[Hg]_{norm}$ = current median concentration of mercury, normalized to percent fines
0.4 µg/g = target median concentration of mercury, normalized to percent fines

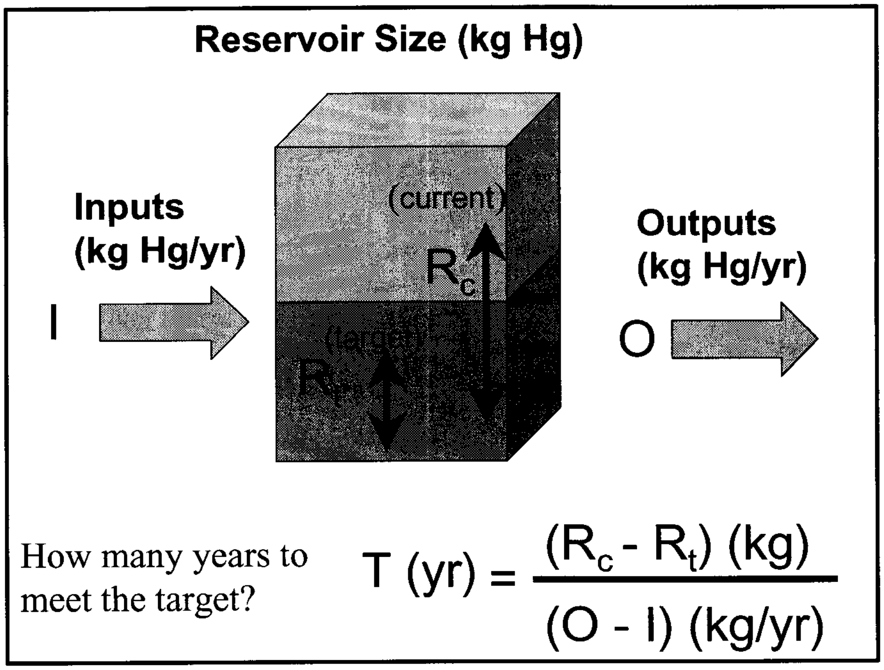


Figure 41: Box model approach to determine time to attain the target. The assimilative capacity is the input rate, I, needed to meet the target in a specified period of time, T

Equation 9 and Equation 10 simply assign numbers to the question, "how many kilograms of mercury are in the active sediments of Lower South Bay today, and how many kilograms will there be once we have attained the sediment target?" Knowing size of the current and target reservoir, we can calculate time it will take (T) to get to the target for any given load reduction. The time to attain the target (in years) is simply the difference between the current and desired targets (kg), divided by the difference between output rates (O) and input rates (I) (kg/year) (Figure 41).

We make the steady state assumption, that output rates equal input rates. With no load reduction, the term O-I reduces to zero, and the time to attain the target becomes infinite. If we don't reduce loads, we will never attain the target. As we get bigger and bigger load reductions, O-I increases, and the time to attain the target decreases. If we eliminate inputs altogether, then the minimum time to attain the target is defined by $(R_c\text{-}R_t)/O$.

Box Model Calculations (E)

(Output-Input) = 38 kg/yr

	Best Estimate	Maximum	Minimum
Time to attain target (yr)	19	44	3
Current Reservoir size (kg Hg)	2869	6885	459
Target Reservoir size (kg Hg)	2165	5196	346

Mercury Reservoir Size (D)

	Total Reservoir Sediment Mass (kg)	Current Average Percent fines	Current Average $[Hg]_{norm}$ (μg/g)	Total Hg in Reservoir (kg)	Target $[Hg]_{norm}$ (μg/g)	Target Hg in reservoir (kg)
Best estimate	7517411	72	0.53	2869	0.4	2165
Maximum	18041786			6885		5196
Minimum	1202786			459		346

Area of Lower South Bay (B)

	Area (m^2)
Best estimate	11,347,035
Maximum	13,616,442
Minimum	9,077,628

Sediment Reservoir Size (C)

	Depth of Active Layer (m)	Volume of sediment reservoir (m^3)	Mass of sediment reservoir (kg)
Best estimate	0.5	5673518	7517411
Maximum	1	13616442	18041786
Minimum	0.1	907763	1202786

Hg Loadings (A)

	Central Valley Watershed	South Bay Watershed	Direct Air Deposition	POTW & Industrial	Total Current Inputs
Best estimate (kg/yr)	6	59	0.70	1.2	67
Maximum (kg/yr)	12	99	1.10	1.5	114
Minimum (kg/yr)	6	14	0.40	0.9	21

Table 31: Box model calculation of time to attain sediment target in Lower South Bay for a net load reduction of 38 kg per year.

The box model calculations for Lower South Bay are shown in Table 31 with the example worked out for a load reduction of 38 kg per year. Section A simply summarizes previously calculated mercury loads to the Lower South Bay segment (Table 24). Section B summarizes estimates for the area of the Lower South Bay. Section C combines those area estimates with estimates for the depth of the actively resuspendable sediment layer to derive the volume of resuspendable sediments. Sediment volumes are converted to sediment masses using Equation 7. Section D calculates current and target reservoirs according to Equation 9 and Equation 10. Section E applies the current and target mercury reservoirs to the Box Model calculation (Figure 41) to determine years to attain the sediment target for a load reduction of 38 kg per year.

The above calculation assumes that output rates stay the same as input rates are lowered. This is a reasonable assumption if the reservoir is much larger than input or output rates, which appear to be the case. This assumption breaks down if loadings approach 15-25% of the reservoir size, as in the case of minimum reservoir size.

Assuming the above assumption holds, the two central questions regarding time to attain the sediment target are:

i) What is the size of the mercury reservoir? The Regional Monitoring Program is already designed to assess the concentration of mercury in sediments and the percentage of fine material, so the main uncertainty about the mercury reservoir is the depth of the actively mixed sediment layer.

ii) What is the maximum feasible possible load reduction? We have estimates of the mercury load coming from the Guadalupe River watershed. Those load estimates can be improved with better monitoring of suspended load. What we really need to know is what can be done to reduce those loads.

The need to address these questions is discussed further under implementation issues (Section 8).

The assimilative capacity is defined as the maximum input rate that the waterbody can handle and still attain the defined numeric targets in a reasonable amount of time. In the context of Figure 41, that means the maximum input rate (I) for a specified time (T). So the assimilative capacity, and thus the required load reductions, will depend on how fast you want to get to the target. The more you reduce loads, the faster you get there.

By our best estimates, the fastest possible time to attain the target is 11 years, if all 67 kg per year of current mercury inputs were eliminated. This is not a feasible scenario, because there will always be some background load due to erosion and atmospheric deposition. If the input rate is reduced from its current level of 67 kg per year down to 29 kg per year, the sediment target will be attained in 19 years, by our best estimates.

We define the assimilative capacity for Lower South Bay in this TMDL as the loading rate that will lead to attainment of the target within fifty years. Based on this definition, our best estimates using the box model approach in Figure 41 show that the assimilative capacity is 29 kg, assuming that current output rates remain constant, and allowing for some uncertainty in the time to attain the target. Mercury control measures in the first phase of the TMDL will be based on these best estimates. We will review and revise those estimates as new information becomes available.

5.6 Assimilative capacity for the entire Bay north of the Dumbarton Bridge

To meet the Clean Water Act requirements for a TMDL, the assimilative capacity must be calculated for the entire Bay, not just the Lower South Bay embayment. In this phased TMDL approach, we propose to regulate to the existing Basin Plan narrative objective for bioaccumulation in the first phase. A numeric target for mercury concentration in sediment was derived from that objective based on the mercury – particle size relationship in sediments source watershed. That numeric target is then evaluated in each bay segment. In each segment, the difference between the current condition and the target condition, multiplied by the annual sediment flux into (and presumably out of) the segment gives the loading capacity (Figure 42).

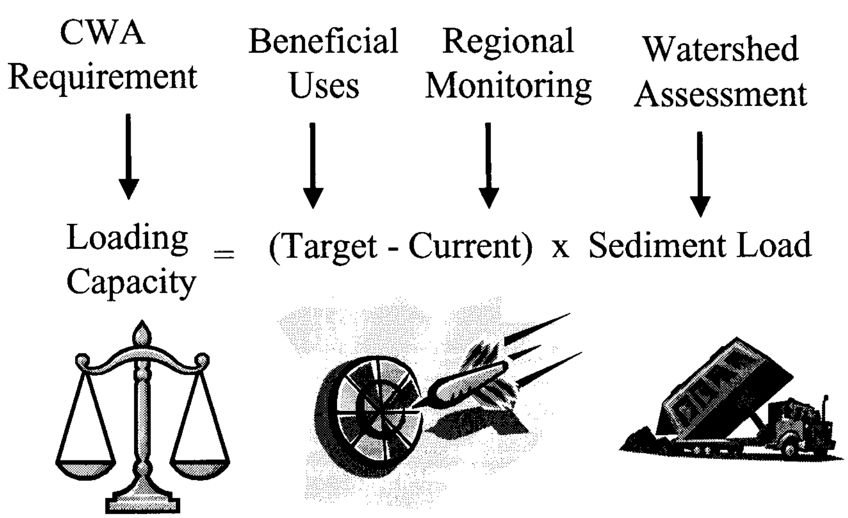


Figure 42: Calculation of loading capacity from a sediment target.

That calculation has been performed for each segment of the Bay north of the Dumbarton Bridge. The results, summarized in Table 32, show that the assimilative capacity for mercury in the Bay north of the Dumbarton Bridge is between 300-1000 kg. It is important to note that the assimilative capacity calculated depends on the definition of the sediment target and the definition for exceedance of that target. Table 32 shows two examples. One is for the case where target exceedance is defined as the median value observed over the target. The second example is for the case where exceeance is defined as the 25'th percentile observed over the target. Thus, the sediment target definition is one of the most critical outstanding issues that needs to be resolved in order to complete and implement the TMDL. Table 32 and Figure 37 concisely show how the sediment target relates to the inferred loading capacity.

Segment	Median	25'th Percentile	Annual sediment flux (kg x 10^6)	Loading Capacity kg (Median)	Loading Capacity (25'th percentile)
B - South Bay	0.37	0.33	1000	30	70
C - Central Bay	0.37	0.31	3700	111	333
D - San Pablo Bay	0.41	0.35	3700	-37	185
E - Suisun Bay	0.35	0.29	3700	185	407
			Total	289	995

Table 32: Loading capacity for segments north of the Dumbarton Bridge.

6. TMDL, Load allocations, and wasteload allocations

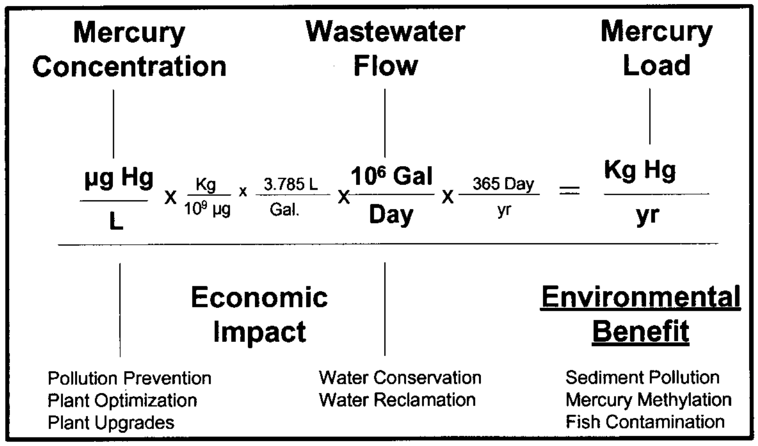
6.1 Approach

In Lower South Bay, the assimilative capacity is defined as 29 kg per year. We allocate that load among all sources in the Lower South Bay segment, including an unallocated reserve, to define a total maximum load to meet the target. Because we are dealing with long-term processes, we express the load in terms of kg per year, rather than a daily load.

For other segments of the Bay, the sediment target is attained. Given the magnitude of the mercury reservoir in the sediments of each segment, wasteload allocations based on assimilative capacity might be higher than desireable for attaining targets in established in the second phase. We still need to exercise some reasonable amount of control over wastewater and urban runoff loads, because we don't have all the information needed to determine factors affecting the methylmercury target. For segments north of the Dumbarton Bridge, we will allocate wastewater loads such that the total mercury load from wastewater sources is less than or equal to 50 kg per year. For urban runoff and other watershed loads, we will assign load allocations based on their current sediment load estimates and the requirement that they meet the sediment target.

6.1.a Wasteload allocations for wastewater discharges

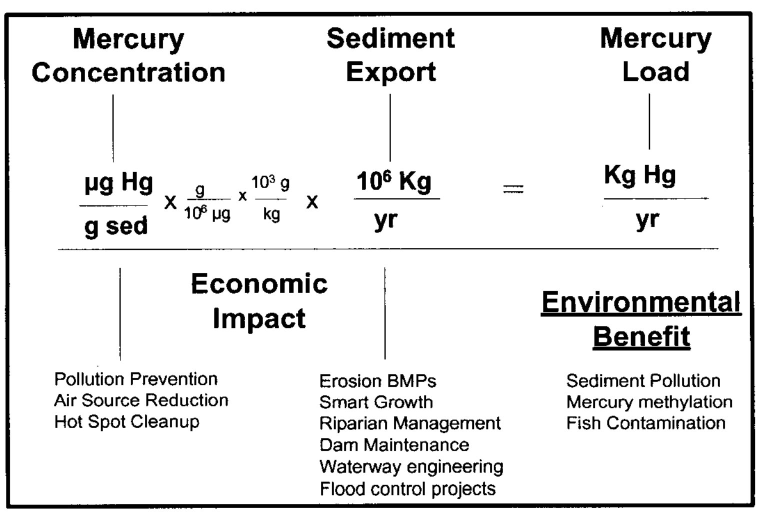
Equation 11



The loads from wastewater discharges vary with mercury concentration in the effluent and effluent daily flow rate (Equation 11). The mercury load assigned to dischargers, individually and collectively, is driven by environmental benefits. However, to adopt this TMDL in the Basin Plan, we have to inform the public and the Regional Board about economic impacts. Those impacts depend on the actions needed to meet load allocations, including water reclamation, plant optimization, and plant upgrades. Therefore, for all municipal and industrial sources, we will state the assumptions about effluent flow and mercury concentration needed to meet the assigned wasteload allocation.

6.1.b Wasteload allocations for urban runoff programs and other watershed sources

Equation 12



Watershed sources are different than wastewater sources. The loads from watershed sources vary with annual sediment load rates and the average mercury concentration of that sediment. As with wastewater loads, the loads assigned to urban runoff and other watershed sources are driven by environmental benefits, but some consideration of economic impacts must be discussed before the public and the Regional Board. Those costs are related to either the cost of reducing sediment production from a watershed or the cost of reducing mercury concentrations in those sediments. Watersheds that drain into the Bay North of the Dumbarton Bridge, will likely be able to meet their assigned loads by simply ensuring that they meet the target for mercury concentrations in sediments. Watersheds the drain into the Bay South of the Dumbarton Bridge, particularly the highly polluted Guadalupe River Watershed, will likely have to focus on both controlling export of contaminated sediments and reducing sediment concentrations of mercury.

6.2 Load and wasteload allocations for Lower South Bay

The assimilative capacity in lower South Bay is estimated to be 29 kilograms per year. That load is allocated among point and nonpoint sources as specified in Table 33. To provide a margin of safety, we have included an unallocated load of 4 kg per year.

Source	Type	Current (kg/yr)	Allocated (kg/yr)
Fremont Bayside	Watershed	2	2
Coyote Creek	Watershed	8	8
Guadalupe River	Watershed	49	4
Palo Alto	Watershed	6	6
Direct Air Deposition	Background	1	1
Unallocated reserve	Background	NA	4
City of Palo Alto	Municipal	0.25	0.6
City of Sunnyvale	Municipal	0.10	0.3
City of San Jose	Municipal	0.80	2.8
FMC Newark	Industrial	?	0.5
	Total	67	29

Table 33: Load and wasteload allocations (kg/yr) for sources in Lower South Bay.

The burden of reduction is placed upon the most egregious mercury source in Lower South Bay, the Guadalupe River watershed, which drains the New Almaden Mining district. The load reduction for that watershed is predicated on implementation of control measures that reduce the median concentration of mercury in sediments transported from that watershed from their current level of 2.5 μg/g to 0.2 μg/g, comparable to adjacent watersheds. The same level of reduction could also be achieved by reducing sediment loads exported from the watershed. Regardless of how the reduction is achieved, we will require attainment of the sediment target of 0.4 μg/g (normalized to fines) for sediments exported from all watersheds, including the Guadalupe River.

The wasteload allocations for the three municipal dischargers in Lower South Bay assume that the treatment plants can maintain an annual average mercury concentration of 0.007 μg/L or less, and that flows increase to no more than double current levels due to growth. Those wasteload allocations, which allow some increase in wastewater loads, are proposed in accordance with U.S. EPA guidance for the development of phased TMDLs: "the phased approach is required when the TMDL involves both point and nonpoint sources and the point source wasteload allocation is based on a load allocation for which nonpoint source controls need to be implemented."[84].

In the implementation plan, we will establish a time to review the TMDL, evaluate progress towards attainment of the load reduction from the Guadalupe River watershed, and decide whether additional, more stringent control measures are needed to attain the target.

It is important to quantify the effects, in terms of reduced environmental benefit, that could result from allowing wastewater sources to increase as watershed sources decrease. For example, consider the purely hypothetical case of a discharger that only needs a pound of mercury. How much difference would one more 1 pound, (0.45 kilograms) make, in terms of attaining the target? If the proposed load reduction of 45 kg is attained, then adding another pound of mercury would add another 3 months to the 17 years required to attain the sediment target. The proposed allocations allow a total increase of 3 kg for all wastewater sources. How does this increase affect the time to attain the target?

Figure 43 shows that the answer entirely depends on the load reduction attained from the Guadalupe River watershed. We propose a reduction of 45 kilograms per year from that watershed. Reserving 4 kg per year as a margin of safety makes the net load reduction 41 kg per year. This would lead to attaining the sediment target in 17 years (Scenario A). An additional 3 kg from wastewater discharges would increase the time to attain the target to 18 years. But what if only 20 kilograms per year are reduced from the Guadalupe River, while point sources concurrently increase by 3 kilograms (Scenario B)? In that case, allowing the growth in point sources would cost an extra 6 years in terms of time to attain the target. And if a mere 10 kilograms per year are reduced from the Guadalupe River Watershed (Scenario C), then what would be the effect of an extra 3 kg? Under Scenario C, the extra mercury from the point sources extends the time to attain the target by 30 years.

It is also worth asking what would happen if we completely ignored the Guadalupe River watershed, and focused instead on reducing wastewater sources, which amount to 1.2 kilograms. Reducing mercury loads in Lower South Bay by 1.2 kilograms might lead to attaining the sediment target in 586 years.

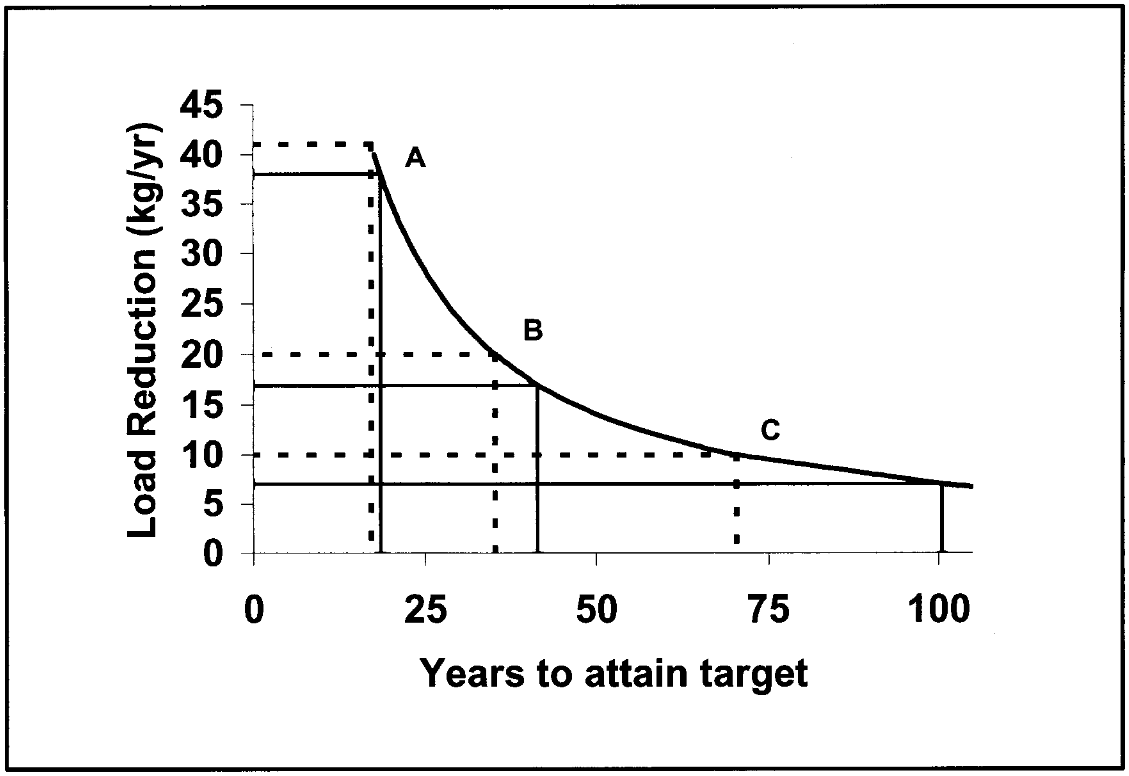


Figure 43: Figure showing the coupling between wasteload allocations for point source discharges in Lower South Bay and the load reduction attained from the Guadalupe River watershed. The dashed horizontal and vertical tie-lines depict load reductions of 41, 20 and 10 kg per year from the Gudalupe River watershed. The solid tie-lines depict the corresponding net load reduction to Lower South Bay if point sources are concurrently allowed to grow by 3 kg.

6.4 Wasteload allocations for wastewater dischargers in all other Bay segments

Of all known sources, wastewater dischargers have attained the most substantial mercury reductions over the past three decades, by investing over two billion dollars in construction of wastewater treatment systems. This report shows that in order to protect beneficial uses, we have to focus on watershed sources. Nonetheless, a complete watershed plan must also put reasonable limits on the mass of mercury released from wastewater sources.

In the Bay Area, current wastewater dischargers release between 25 and 63 kg of mercury per year. We have recently required better mercury measurements from all wastewater dischargers, and expect this estimate to be refined to 15-40 kg per year as new data are produced. Even though Bay segments north of the Dumbarton Bridge appear to be below their assimilative capacity, some level of control on point sources is needed to protect beneficial uses.

The sum of wasteload allocations for wastewater should be less than 50 kg in the entire San Francisco Bay watershed. This mass is derived from the sediment budget for San Francisco Bay (Table 15) and the Basin Plan narrative objective for bioaccumulation: "Controllable water quality factors shall not cause a detrimental increase in concentrations of toxic substances found in bottom sediments or aquatic life."

Every year, 3.7 billion kilograms of sediment are deposited in San Francisco Bay. If we limit total wastewater mercury loads 50 kg or less, the mercury concentration of bottom sediments would be at most 0.013 mg/kg higher than they would be in the absence of wastewater loads. Thus, the proposed limit for wastewater makes two assumptions:

1) Mercury loads from wastewater are entirely adsorbed onto sediments (an environmentally conservative assumption);
2) 0.013 mg/kg is not a detrimental increase in the mercury concentration of bottom sediments, which average 0.3 mg/kg in San Francisco Bay.

This proposed load should be allocated to individual sources according to the vulnerability of the receiving waters. Shallow receiving waters have longer residence times, and are more prone to the suboxic conditions that promote mercury methylation. Therefore, shallow water discharges should get proportionally lower wasteload allocations that deep water discharges.

We have also considered technological feasibility in allocating individual loads. A recent study by the Association of Metropolitan Sewage Agencies (AMSA) using modern analytical techniques shows that 90 percent of the effluent mercury values in the dischargers examined were at or below 0.015 μg/L. Therefore, we can reasonably expect that any treatment plants in the Bay Area to maintain an annual average effluent concentration of 0.025 μg/L or less. Plants with shallow water outfalls to should show better performance, because their receiving waters are more vulnerable. Based on the AMSA study, we can reasonably expect plants with shallow water outfalls to maintain meet an annual average effluent concentration of 0.015 μg/L or less.

We have derived individual WLAs using these two performance goals (0.025 μg/L and 0.015 μg/L), and double current flow rates. The sum of these mass limits for all municipal and industrial dischargers is less than 50 kg. This approach limits total masses of mercury released from wastewater discharge to levels very close to current performance, while allowing reasonable room for growth and placing the burden of increased treatment on facilities with the poorest performance. We will continue to investigate possible linkages between wastewater inputs and methylmercury production. As we refine the methylmercury target and gain a better understanding of methylmercury distributions in the estuary, it may be necessary to impose more stringent mass limits on individual wastewater dischargers in the second phase.

Wasteload allocations for municipal dischargers are summarized in Table 34, Figure 44, and Figure 45. Wasteload allocations for industrial dischargers are summarized in Table 33 and Figure 46.

Facility	Bay Segment	Map Key	Wasteload Allocation (kg/yr)	Best Estimate of annual flow (MGD)	Annual average mercury concentration target (µg/L)
San Jose/Santa Clara WPCP	A	23	2.8	120.1	0.007
East Bay MUD	C	9	6.4	77.3	0.025
EBDA, East Bay Dischargers Authority	B	8	6.4	76.8	0.025
City & Co. of S.F., Southeast	B	21	6.2	75.0	0.025
Central Contra Costa S.D	E	4	3.8	45.8	0.025
City of Palo Alto	A	19	0.6	25.7	0.007
So. Bayside System Authority	B	29	1.7	20.7	0.025
West County Agency	C	34a	1.4	16.5	0.025
City of Sunnyvale	A	32	0.3	14.6	0.007
Napa S.D.	D	15	0.7	14.2	0.015
Delta Diablo S.D.	E	7	0.7	13.6	0.015
City of San Mateo	B	24	1.1	13.1	0.025
Fairfield Suisun Sewer Dist.	E	10	0.6	12.8	0.015
Vallejo Sanitation & Flood Cont.	D	33	1.0	12.5	0.025
LAVWNMA, Livermore-Amador Valley WMA	B	8a	0.9	11.0	0.025
Central Marin Sanitation A.G.	C	5	0.9	10.9	0.025
So. S.F./ San Bruno WQCP	B	30	0.8	10.2	0.025
City of Petaluma	D	20	0.5	10.1	0.015
West County Wastewater Dist.	C	34b	0.6	6.7	0.025
Novato S.D.	D	17	0.3	6.1	0.015
City of Burlingame	B	2a	0.3	4.1	0.025
Sewerage Agency of So. Marin	C	27	0.3	3.1	0.025
Sonoma Valley County S.D.	D	28	0.1	2.8	0.015
City of Pinole	D	11a	0.2	2.3	0.025
City of Benecia	E	1	0.2	2.3	0.025
City of Millbrae	B	2b	0.2	1.9	0.025
Las Gallinas Valley S.D.	D	12	0.1	1.7	0.015
Mountain View S.D.	E	14	0.1	1.5	0.015
Sausalito-Marin City S.D.	C	25	0.1	1.4	0.025
City & Co. of S.F., Int. Airport	B	2c	0.1	0.9	0.025
Marin Co. S.D. #5	C	13	0.1	0.8	0.025
Rodeo S.D.	D	11b	0.1	0.7	0.025
City of Calistoga	D	3	0.0	0.6	0.015
City of Hercules	D	11c	0.0	0.4	0.025
Town of Yountville	D	35	0.0	0.4	0.015
City of St. Helena	D	31	0.0	0.3	0.015
Contra Costa Co. S.D. No. 5	E	6	0.0	0.0	0.025
Total			40		

Table 34: Summary of annual wasteload allocations for muncipal dischargers in the San Francisco Bay region.

Facility	Bay Seg-ment	Map Key	Wasteload Allocation (kg/yr)	Best Estimate of annual flow (MGD)	Annual average mercury concentration target (µg/L)
C&H Sugar Co.	D	2	2.0	24.5	0.025
Chevron U.S.A.	D	3	0.5	6.0	0.025
Equilon Enterprises LLC.	E	8	0.4	5.3	0.025
Tosco Corp. Avon Refinery	E	11	0.4	4.3	0.025
Dow Chemical Co.	E	4	0.2	2.2	0.025
Exxon	E	5	0.2	1.9	0.025
Tosco Corp. Rodeo Refinery	D	12	0.1	1.6	0.025
San Francisco Int. Airport	B	16	0.1	0.9	0.025
General Chemical Corp. Bay Point Works	E	1	0.0	0.3	0.025
Rhone Poulenc Basic Chemical Co.	E	9			0.025
Zeneca Agricultural Products	C	10			0.025
USS Posco	E	13	0.8	9.1	0.025
FMC Newark	A	6	0.5		
PG&E Portrero Power Plant	B	13	0.1	202.0	0.0002
GWF Power System, Nichols Road Power Plant	E	14	0.0	0.0	0.025
GWF Power System, East Third Street Power Plant	E	15	0.0	0.1	0.025
Total			4.8		

Table 35: Summary of annual wasteload allocations for industrial dischargers in the San Francisco Bay region.

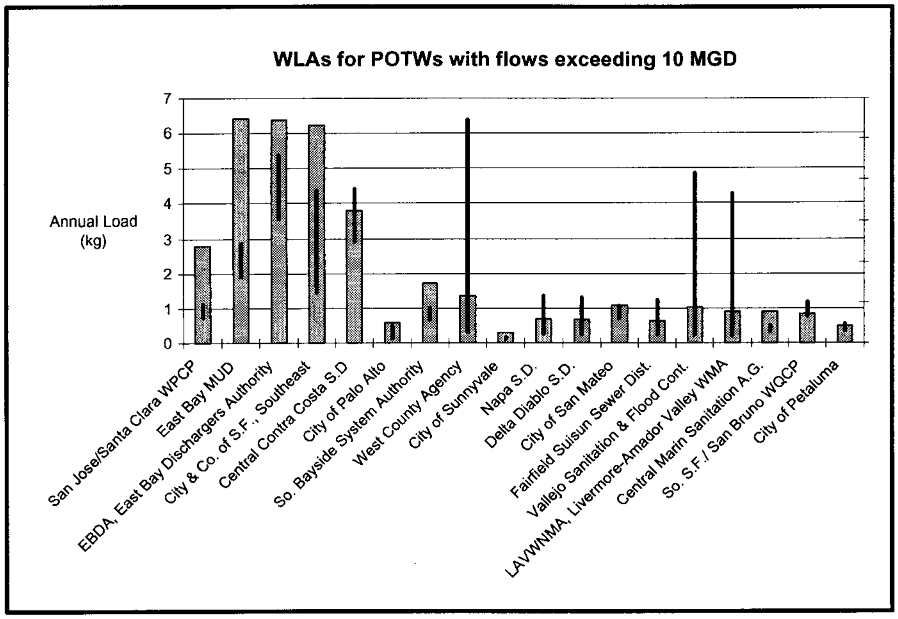


Figure 44: WLAs (solid Grey bars) and current performance (black vertical lines) of municipal wastewater dischargers with flows exceeding 10 million gallons per day.

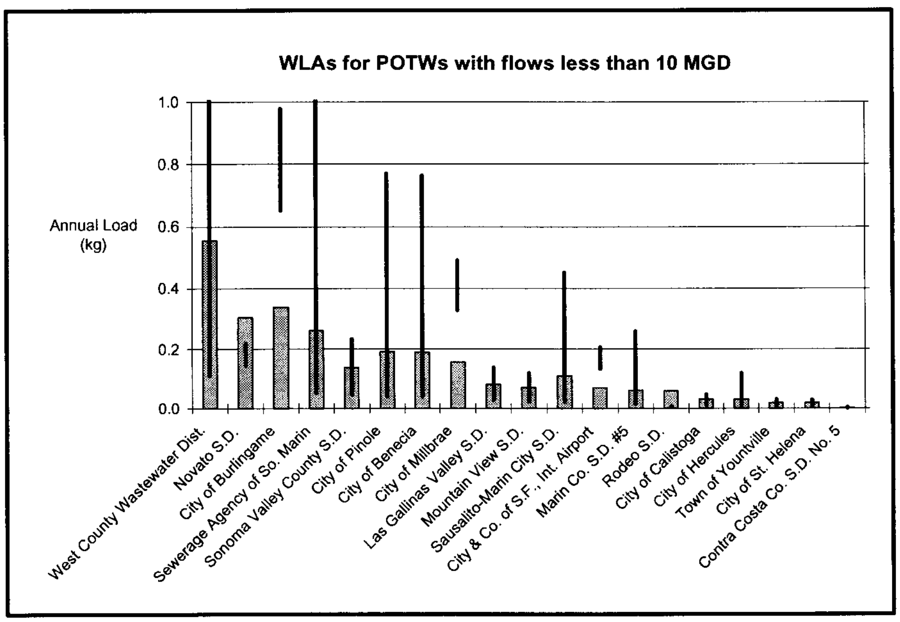


Figure 45: WLAs (solid Grey bars) and current performance (black vertical lines) of municipal wastewater dischargers with flows less than 10 million gallons per day.

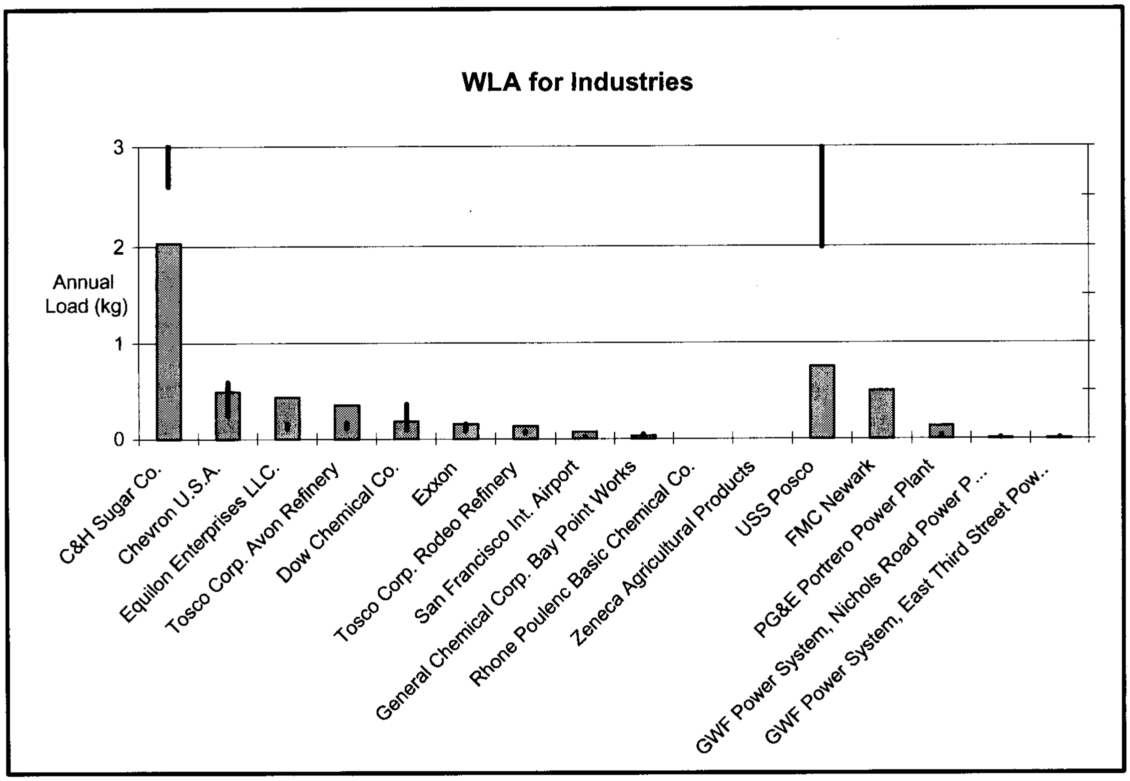


Figure 46: WLAs (solid Grey bars) and current performance (black vertical lines) of industrial wastewater dischargers.

6.5 Wasteload allocations for urban runoff programs

Urban runoff programs convey sediments from surrounding watersheds, through urban environments, and into San Francisco Bay. Urban runoff programs have traditionally been managed through implemenatation of Best Management Practices (BMPs), rather than numeric, end-of-pipe objectives. Under this TMDL, we will expect urban runoff programs to go beyond the scope of past BMPs in order to directly address links between urban runoff and the numeric targets in this TMDL. Still, our implementation plan should reasonably account for the differences between urban runoff and treated wastewater.

The most likely sources of mercury in urban runoff are airborne deposition and conveyance of mercury-contaminated sediments from sources in the watershed. Since urbanized areas very likely convey airborne mercury fallout much more efficiently than undeveloped areas, it is in the best interests of urban runoff programs to participate in air source monitoring and reduction. The next section (Section 6.6) discusses the load allocation for air sources.

In the first phase of the TMDL, we will ask urban runoff programs to participate in reduction of air emissions of mercury through a voluntary, partnership approach.

Participation to help reduce air sources may include lobbying the electric light industry for the reduction of mercury emissions from fluorescent lights through product reformulation, coordination with solid waste management agencies to ensure 100% recycling of fluorescent lights, or partnering with known or suspected combustion sources to quantify emissions and implement pollution prevent measures to reduce those emissions.

At the end of the first phase, during the TMDL review, the participation and success of the urban runoff programs will be carefully scrutinized. If no progress has been made towards reducing air sources, more prescriptive measures may be adopted, including numeric limits that are linked to the production of methylmercury in the Bay. During the first phase of the TMDL, staff will be working to rigorously define the links between atmospheric deposition, urban runoff, and mercury methylation. We will direct the urban runoff programs to investigate the bioavailability of mercury in urban runoff loads, to participate in the assessment of atmospheric deposition of mercury, and to assist in development of a numeric model for mercury cycling in San Francisco Bay.

The Bay Area Stormwater Management Agencies Association (BASMAA) has already begun a study of mercury in fuels. BASMAA has also contributed towards the Regional Monitoring Program's Atmospheric Deposition Pilot study. These actions demonstrate that monitoring needs can be addressed through the partnership approach. We anticipate that reductions of air sources can also be attained through a cooperative approach. However, submission of this TMDL report to the U.S. EPA, and the policy action that will result from bringing the TMDL before the board for adoption, serves notice to the regulated community that we intend to reduce air emissions of mercury in this region. This is a mandate that has been clearly delivered by stakeholders in the mercury council, and in public comments to the Regional Board, and it is supported by the best available research on mercury biogeochemical cycling.

Monitoring, modeling, and reduction of air sources are all directed at the methylmercury target. We also expect urban runoff programs to address the sediment mercury target. In order to maximize resource efficiency, we will ask the urban runoff programs to begin by reporting the sediment mercury concentrations and percentage of fine material at the base of their watersheds, above the tide line. If the median value of sediments entering the Bay is consistent with the sediment target, that effort may be sufficient. If, however, there is evidence for delivery of mercury enriched sediments from a watershed, as evidenced by exceedance of the sediment target, we will direct the urban runoff programs to conduct upstream source identification, to isolate the source of mercury-enriched sediment. We will also work with the urban runoff monitoring programs to ensure that their field collections address other sediment-bound pollutants; this is particularly important for PCB's, which will also eventually be regulated through a TMDL, and which have known or suspected watershed sources.

Monitoring and control directed at the sediment target is particularly important for the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP), which discharges water into Lower South San Francisco Bay. It is very likely that the urban development in the Guadalupe River Watershed has helped spread mercury-enriched sediments throughout the lower watershed. We expect SCVURPPP to investigate this hypothesis, and to take any control measures necessary to help meet the load allocation assigned to Lower South Bay.

All watershed sources, both urban and non-urban runoff, must meet the mercury sediment target (0.4 µg/g, normalized to percent fines). In watersheds where the target is exceeded, we propose to conduct source investigations and issue waste discharge requirements to control sources as needed. Urban runoff programs are responsible for ensuring that their stormwater conveyances also comply with the sediment target.

The numerical wasteload allocation, in kg per year, for an urban runoff programs depends on the sediment load conveyed. That load, in turn, varies with annual rainfall. To derive a rigorous numeric wasteload allocation for a particular urban runoff point of discharge, we would need information on the sediment load from that point. In the absence of such information, we simply hold urban runoff programs responsible for ensuring that the sediment target is attained in the receiving waters impacted by their conveyances.

In other words, we assign a load allocation to each of the sub-watersheds shown in Figure 28 based on estimated sediment production. The load from each of those subwatersheds is the sum of both urban runoff wasteloads and background watershed loads. In the first phase of the TMDL, we propose to hold urban runoff programs responsible for attaining the load allocation for all watershed catchements in their jurisdiction. If an urban runoff management agency wishes to develop a separate wasteload allocation for their urban stormwater conveyances, they must provide reasonable estimates of the sediment load from those conveyances, and assess compliance with the sediment mercury target. The load allocations for watershed catchments in the San Francisco Bay Region are shown in Table 36.

Box Model Segment	Hydrologic area code	Hydrological area name	Mercury load allocation (kg) for a given rainfall year 10'th %'tile	avg.	90'th %'tile
B	220420	East Bay cities	2.4	4.5	6.5
B	220430	Alameda Creek	3.5	7.7	9.6
B	220440	San Mateo - Bayside	1.7	3.1	4.2
C	220320	San Rafael	1.0	1.4	2.3
C	220330	Berkeley	0.5	0.9	1.4
C	220340	San Francisco - Bayside	0.2	0.3	0.4
D	220620	Novato	1.1	2.4	3.7
D	220630	Petaluma River	4.2	7.6	9.6
D	220640	Sonoma Creek	6.1	9.3	14.1
D	220650	Napa River	8.6	17.0	28.1
D	220660	Pinole	0.8	1.4	1.6
E	220721	Fairfield (220721)	1.1	2.0	2.4
E	220722	Fairfield (220722)	0.6	1.2	1.2
E	220723	Fairfield (220723)	5.5	8.6	11.8
E	220724	Fairfield (220724)	0.1	0.2	0.3
E	220731	Concord (220731)	1.4	2.0	3.4
E	220732	Concord (220732)	0.6	0.9	1.5
E	220733	Concord (220733)	0.4	0.7	0.9
E	220734	Concord (220734)	0.2	0.3	0.5
		Total	40	71	104

Table 36: Load allocations for watershed catchments in the San Francisco Bay Region. Allocations are derived using Equation 12 based on sediment loads from the Coastal Mass Watershed Loading Project[50] and assuming that a bulk sediment mercury concentration of 0.32 µg/g is attained (i.e., the sediment target of 0.4 µg/g normalized to percent fines, and an average of 80% fines).

6.6 Load allocations for Air Sources

Mercury releases into the atmosphere amount to 370 kg per year. This TMDL, when adopted, will require reduction of atmospheric mercury releases by 70 kg per year. This is a reduction attainable through control of emissions from fluorescent lights alone. However, we are not insisting on control of fluorescent lights, but rather suggesting it as one of the most effective, readily implemented measures. The Pollution Prevention Workgroup of the San Francisco Bay Mercury Council has identified other air emission sources that also offer opportunities for reduction. Consistent with the provisions of the State Water Code, we are specifying the amount of air emission reductions we want, but not the means of compliance.

The Regional Board has not traditionally regulated air sources. However, based on the linkages between air emissions of mercury and mercury bioaccumulation in other aquatic ecosystems, we find this is an appropriate measure directed at protection of beneficial uses. The regulated parties most affected by airborne deposition are urban runoff programs. As discussed above, we seek the participation of the urban runoff programs in a partnership approach in the first phase of the TMDL to better quantify air emissions, reduce mercury releases by 70 kg per year, and develop a numeric model quantifying the links between atmospheric emissions and mercury methylation. If these goals are not attained during the first phase of the TMDL through a partnership approach, more prescriptive measures will be adopted in the second phase.

6.6 Load allocations for the Central Valley Watershed

Similar to the urban runoff programs, we derive a load allocation for the Central Valley Watershed in the first phase of the TMDL that is based on the sediment target. Therefore, proposed load allocation is equal to the current load: 558-1150 kg per year, depending on flow conditions and sediment export rates.

During the first phase of the TMDL, we will continue to work with the Central Valley Regional Board to assess mercury sources that may contribute to exceedance of either the sediment or the methylmercury target. In the second phase, we will review the TMDL and establish new load allocations as necessary.

7. Margin of Safety, Seasonal Variations, and Critical Conditions

7.1 Margin of Safety

The margin of safety can be derived implicitly, through conservative assumptions about the numeric targets and finding of impairment, or explicitly, through reservation of unallocated load. In this TMDL report, we adopt both approaches.

The numeric target for dissolved methylmercury related to the FDA action level of 1 µg/g mercury in fish is 0.1 ng/L. Our first implicit margin of safety is that we estabslish a numeric target at half of this level, 0.05 ng/L methylmercury in water. This is the lowest published target related to protection of wildlife. The reasoning is that by regulating to protect wildlife, which feed essentially 100% out of the Bay, we will also be protecting humans who rely on the Bay for food. Although the Bay as a whole is below this target, we retain the finding of impairment, pending additional investigation of dissolved methyl in the tributaries and margins of the Bay. This is our second implicit margin of safety, which ensures continued control of all mercury sources on a watershed scale.

In Lower South Bay, the Total Maximum Annual Load includes an unallocated reserve of 4 kg, or 13% of the loading capacity. This is part of our explicit margin of Safety. The other part of our explicit margin of safety is the time to attain the target. By our best estimate, the sediment target in Lower South Bay will be attained in 19 years. The maximum time to attain that target is 44 years, which is still a reasonable period of time for a legacy pollutant that was first mobilized in our watershed over a hundred years ago.

7.2 Seasonal Variation

Load calculations for the Sacramento River and for benthic remobilization are derived from the sediment budget for San Francisco Bay (Figure 27) and measurements of mercury concentrations in sediments. The loading rate from the Sacramento River varies with flow. As flow increases, suspended load increases, as well as the mass of sediment transported per unit time. The relationship between flow and sediment flux is complex [85]. For a given flow rate, the amount of sediment transported can vary by a factor of nearly 100. The first major flows following a dry season tend to transport more sediment than comparable flows later in the year. Peaks in suspended load tend to lead peaks in streamflow. We can make the generalization that wet periods will have larger sediment loads than dry periods, but how can we use that complex relationship quantitatively in a TMDL analysis?

This is a critical question, because the Sacramento River plays such a dominant role in sediment and trace metal transport. Both sediment import and export rates are flow dependent, so the resultant assimilative capacity also varies with the flow. Assuming that the assimilative capacity will be used up during high flow periods mistakenly ignores the fact that mercury is removed from the system faster during high flow. We could attempt to derive an assimilative capacity that is expressed as a function of flow. A complex autocorrelation function has been derived that expresses the dependence of flow and sediment data on previous hydrologic conditions [85]. But that approach makes implementation exceedingly difficult, as it could lead to flow-dependent mass limits for point sources.

To translate the inferred loads into a TMDL, we have to think about long-term averages. The TMDL is expressed as mass per unit time. In San Francisco Bay, it doesn't make sense to talk about daily loads, because of our wet and dry seasons. Annual loads make more sense, but only if we consider long-term averaging periods. For example, in this analysis we use the range of sediment inflow from the Central Valley Basin (6.9-8.1 million cubic yards) to describe the loading from the Sacramento River. Likewise, the watershed loadings are also based on precipitation patterns averaged over long periods of time.

Watershed management takes place on decadal time scales. This is necessary to account for the wide range of annual precipitation fostered by the El Nino weather cycles in the west coast, and appropriate to managing a legacy pollutant that has been around for over one hundred years. This is also why we consider annual average concentrations when evaluating wastewater loadings. Mercury cycling in the San Francisco Bay aquatic ecosystem responds to changes on relatively long timescales, and our management actions have to reflect that reality.

7.3 Critical Conditions

There are two critical conditions likely to affect mercury cycling: the prolonged droughts, and the annual phytoplankton bloom. Prolonged droughts affect the residence time of both the northern reach and the southern reach, and increase salinity in the Bay. The effect of this on mercury cycling is unknown, but needs to be characterized during the first phase of the TMDL. Suboxic conditions can be triggered by the annual spring phytoplankton bloom in the South Bay. This could enhance methylation rates, so it also merits additional attention.

8. Outstanding Issues and Implementation Mechanisms

8.1 Outstanding Issues

The following is a list of issues for which we would like resolution, either by the time the TMDL is finalized (<1 year) or as part of the TMDL implementation (>1 year). We plan to use this list as a starting point to develop the Implementation Plan for the TMDL that will be a part of the Basin Plan amendment.

Category	Issues	Work in Progress or ***Work needed*** to assist resolving issue	Who is doing (***or might do***) the work	Resolution Timeframe	
				< 1 year	> 1 years
Targets	1. How accurate is the BAF value of 10^7 used to calculate the MeHg in water target for SF Bay environment? If not, MeHg target level should be revised.	***Need study to determine BAF for SF Bay to refine MeHg in water target***	***(RMP)***		■
	2. Compliance with 0.05 ng/l MeHg in water target based on very limited data.	On going RMP monitoring for total and methyl mercury at fixed stations.	RMP	■	■
	3. Is there compliance with the MeHg target in the shallower areas and Bay margins? If not, this may suggest sensitive areas with higher methylation potential (i.e. areas to focus further Hg reductions efforts).	***Need MeHg data of water in Bay shallows and margins***	***(RMP)***		■
	4. Fish tissue target is a more direct indicator than MeHg in water for fish consumption. What is an appropriate fish tissue target to protect human health?	NAS currently in the process of determining safe dietary exposure limits	NAS	■	

Category	Issues	Work in Progress or ***Work needed*** to assist resolving issue	Who is doing (***or might do***) the work	Resolution Timeframe	
				< 1 year	> 1 years
	5. What is the appropriate fish consumption rate to use for deriving target fish tissue levels for the Bay Area population and in particular for subsistence fishermen?	DFG and DHS survey on fish consumption patterns in the Bay Area nearly complete	DHS/DFG	▬	
Targets (cont.)	6. Are Bay Area wildlife adequately protected (or overly protected) by the national number of 0.05 ng/l MeHg in water from the Report to Congress? In particular, are resident endangered species of waterfowl protected?	***Need avian egg target.*** On going work initiated by Regional Board with FWS to determine Hg levels in Bay Area avian eggs. Also in place is a CALFED study to determine dose response relationship of Hg in avian eggs.	FWS, CALFED, SFB-RWQCB.	▬	▬
	7. What are good targets for wetlands and dredging management polices? MeHg in sediments? MeHg:TotHg ratios?	***Need understanding of methylation and demathylation processes and the factors that affect them.***			▬

Category	Issues	Work in Progress or ***Work needed*** to assist resolving issue	Who is doing (***or might do***) the work	Resolution Timeframe	
				< 1 year	> 1 years
Source Inventory	1. What is the cause of sediment target exceedances in San Pablo Bay? Tributary inputs (e.g., Napa, Sonoma, Petaluma? Or resuspension of in-bay sediment from historic gold mining?	**Need studies to determine depth of active sediment layer, and studies to discern any gradients leading to the tributaries.** Partly addressed by CALFED study funded in part by SFBRWQCB on MeHg and tot Hg in sediments throughout Bay Area. Due out summer 2000.	***(RMP, USGS)*** SFB-RWQCB/ CALFED		
	2. What is the cause of the sediment (and possibly MeHg in water) target exceedances from San Joaquin River? Unique to SJ watershed because of geology? Or because of controllable inputs from historic mines?	***Need studies to identify causes.***	***(Delta Hg TMDL, Marsh Ck. TMDL, CV RWQCB)***		
	3. Air deposition loading estimate based on general assumptions and deposition rates from other areas, which may not be accurate for the Bay Area.	On going RMP air deposition study.	RMP		
Source Inventory (cont.)	4. Air emission estimates based on general emission factors. Estimate can be improved if there are data from source testing.	• Verify emission estimates from 3 highest stationary sources. • Revise mobile combustion using BASMAA study of fuels.	***(Facilities or BAAQ MD)*** BASMAA		

Category	Issues	Work in Progress or ***Work needed*** to assist resolving issue	Who is doing (***or might do***) the work	Resolution Timeframe	
				< 1 year	> 1 years
	5. Simple assumptions (0.1-1% off rural, 10-50% off urban) used to estimate indirect air deposition to Bay water. These can be improved to provide better estimates.	***Develop a more refined numeric model to estimate indirect air dep.***	(BASMAA)		■
	6. Wastewater point source loadings estimated using detection limits and assumptions about discharge values for some dischargers.	Measurements by all wastewater point sources since Jan 1, 2000, will provide data to amend, as necessary the loading calculations based on actual values.	Individual dischargers.	■	
	7. Watershed source loads based on general land use and runoff factors. These can be improved with field measurements.	***Estimate mass loading through storm monitoring of sediment loads and Hg concentrations as necessary.***	Urban runoff permittees		■
	8. Not all sources are created equal. Future reduction strategies should focus on sources that contribute the most methylatable mercury.	***Need to understand the bioavailability of different sources of mercury.*** In part will be addressed by CVRWQCB study that is underway to evaluate bioavailability.	CV-RWQCB		■
	9. What is the magnitude of MeHg from sediment contamination sites (Toxic Hot Spots) compared to ambient methylation rates? If significant, will need a Load Allocation in Phase II.	Site investigation to assess methylation rate and process.	Responsible parties		■

Category	Issues	Work in Progress or ***Work needed*** to assist resolving issue	Who is doing (***or might do***) the work	Resolution Timeframe < 1 year	Resolution Timeframe > 1 years
Imple-menta-tion of WLA and LA in Phase I	1. Guadalupe River identified as a large source to Lower So. Bay. Need better delineation of sources to develop reduction strategies for each.	• Improve definition of watershed sources and their bioavailability: ○ Mines ○ Urban runoff (incl. Air dep.) ○ Instream sediments ○ Reservoirs • Develop reduction control measues and cost estimates.	Guadalupe River Watershed TMDL	■	■
	2. Some wastewater point sources (about ¼ to↦) not within allocated loads based on current data. What should be required?	• Improve data using ultra clean analys. • ***Compliance schedule in permits to:*** ○ ***Investigate influent sources*** ○ ***Investigate in-plant sources, and*** ○ ***Investigate potential for localized impacts from discharge***	Discharger, ***SFB-RWQCB and discharger***	■	
	3. Urban runoff allocation is lumped with general watershed allocation. How will urban runoff compliance be measured if non-urban runoff (or other watershed source is a bigger cause of the problem?	*Develop permit mechanism to require where necessary:* • Quantification of Hg sed conc. to distinguish urban from other source • ***Identification of sources in urban environment, their bioavailability, and investigate linkages to aquatic systems***	SFB-RWQCB ***(BAS-MAA and urban stormwtr permittee)***	■	

Category	Issues	Work in Progress or ***Work needed*** to assist resolving issue	Who is doing (***or might do***) the work	Resolution Timeframe	
				< 1 year	> 1 years
Phase I WLA/LA Imple-menta-tion (cont.)	4. How will air source loads reductions be achieved since there is no clear responsible party identified in the TMDL?	***Identify opportunities for reduction through watershed partnership with existing stakeholders.*** BADA currently funded initial assessment of fluorescent bulbs recycling/substitution by Sustainable Conservation. Work noted above for urban runoff and air emission estimates may help to identify other responsible parties for participation in partnership.	various		
	5. Annual loads allocated for sediments from non-point sources may be problematic in assessing compliance since sediment loads vary annually due to weather more than load reduction successes or failures.	Develop permit language for determining compliance with allocated loads based on compliance with sediment target only.	SFB-RWQCB		
	6. A WLA that allows for increase discharges (2 X current flow) for any source to already impaired waters is inconsistent with a strategy to fix the impairment.	***Develop a numeric model to show linkages and impacts of various sources based on bioavailability, local methylation rates, etc.***	***(Wastewater dischargers)***		
Phase II WLA/LA Imple-menta-tion	1. Central Valley loads may contribute to exceedance of targets to be set in Phase II.	CVRWQCB is in process of developing a TMDL. One of the elements of this will be an assessment of the bioavailability of the sources which will assist us in determining the potential contribution of methylatable Hg from the central valley.	CV-RWQCB		

Category	Issues	Work in Progress or ***Work needed*** to assist resolving issue	Who is doing (***or might do***) the work	Resolution Timeframe	
				< 1 year	> 1 years
Phase II WLA/LA Imple-menta-tion (cont.)	2. Potential conflict in goals may exist between Bay TMDL and Guadelupe River Watershed TMDL. Need to identify these conflicts.	Identify conflicts are they come up and work toward a coordinated resolution.	SFB-RWQCB		
	3. After more data are available to allow further evaluation of compliance with MeHg target in the Bay, wastewater sources discharging to highly sensitive areas may be allocated reduced loads.	**Develop mass offset strategy for trading with:** • ***Local storm water sources,*** • ***Watershed sources.***	SFB-RWQCB/ discharger		

8.2 Implementation Mechanisms

There are several mechanisms for implementing the monitoring and control measures required by this proposed watershed management strategy. State Waste Discharge Requirements and Cleanup and Abatement orders can be used to directly address mercury sources from polluted sites in watersheds. NPDES permits can incorporate proposed wasteload allocations. Monitoring and analysis needed to develop additional information can be required by issuing 13267 letters. We will continue to work with stakeholders through the Mercury Watershed Council to craft language for these and other items needed to develop an implementation plan.

Action	Goal	Responsible or affected party
Waste Discharge Requirements	Control of mercury mobilized from upper Guadalupe Watershed	Santa Clara County Parks
Cleanup and Abatement Order	Control of mercury mobilized from upper Guadalupe Watershed	Santa Clara County Parks
Waste Discharge Requirements	Control of mercury mobilized from lower Guadalupe Watershed	Santa Clara Valley Water District
Cleanup and Abatement Order	Control of mercury mobilized from lower Guadalupe Watershed	Santa Clara Valley Water District
NPDES permits	Require specific monitoring directed at sediment target, adopt mass limits with permit language specifying compliance evaluated using sediment target	Urban runoff programs
NPDES permits	Adopt mass limits	All NPDES wastewater dischargers, BADA, WSPA
13267 letter	assess bioavailability of mercury in wastewater sources	All NPDES wastewater dischargers, BADA, WSPA
13267 letter	assess bioavailability of mercury in urban runnof sources	Urban runoff programs
13267 letter	Assess mercury concentrations in sediments, percent fines	Urban runoff programs
13267 letter	Develop numeric model for mercury methylation	BADA, BASMAA, WSPA, others

Table 37: Regulatory mechanisms for implementing the proposed watershed management plan for mercury in the San Francisco Bay Region.

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