Strategic Plan for the Reduction of Mercury-Related Risk in the Sacramento River Watershed

Mercury Pollution in Northern California

Delta Tributaries Mercury Council

SACRAMENTO RIVER WATERSHED PROGRAM

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Executive Summary

This document describes the key elements of a Strategic Plan ("Plan"), developed by the Delta Tributaries Mercury Council (DTMC) with support from the Sacramento River Watershed Program (SRWP). The objective of this Plan is to reduce the accumulation of mercury by fish through actions within specific areas of the Sacramento River watershed (SRW). Some actions are pilot projects that are highly specific and limited in area because no field studies have shown that controls are effective enough to reduce fish tissue concentrations below the target level. To characterize the mercury issues and to lay out a recommended course of action for dealing with those issues, the following fundamental and subsidiary management questions are addressed:

❑ Fundamental Question #1: What is the nature and extent of the human health and ecological risks caused by mercury in the SRW and downstream waters?

This question leads to a description and evaluation of the problem, through the following subsidiary questions:

- **What are the existing health risks of mercury to humans and wildlife in the SRW?** Methylmercury is the most toxic and bioaccumulative form of mercury. According to the US Environmental Protection Agency (USEPA), pregnant women eating more than 17.5 grams per day (0.6 ounces/day) of fish with 0.3 milligrams or more of methylmercury per kilogram of fish tissue (mg/kg) have an increased probability that adverse effects may be observed in their unborn children. Health risks to wildlife are species-specific and largely unknown. The mercury risk to fish-consuming wildlife in the SRW is presumably dependent on fish consumption rates and mercury levels in major prey species. Since there is no definitive information available on feeding habits or consumption rates, it is not possible to make meaningful statements regarding the risk to wildlife.
- **What is an appropriate target level of mercury in fish?** USEPA recommends a target of an average of no more than 0.3 milligrams (mg) methylmercury per kilogram (kg) of fish tissue to avoid mercury risk in the human population. At this target level, there likely would be no observable adverse effects to children or adults if locally caught fish are consumed at a rate of < 17.5 g/day (< 0.6 oz/day). Although this target level has been assumed to reduce risk to wildlife to an acceptable level, recent information may indicate otherwise.

❑ Fundamental Question #2: How well understood is the nature of mercury risk and the ability to reduce it?

This question leads to a process of describing the available information, our understanding of the problem's scope and our ability to address it. A linkage analysis is presented as a framework for understanding the links in the causal chain between sources and exposure. The following subsidiary questions are addressed in that context:

- **How effective is source control at reducing mercury concentrations in target species?** In the SRW, source loadings are generally only grossly quantifiable. Source control effectiveness is highly site-specific and dependent on the source's concentration and relative contribution to total loadings.
- **How do fate and transport processes impact mercury concentrations in downstream locations?** Mercury may be physically, chemically, and biologically transported, transformed, and entrapped, or otherwise modified in quantity or character as it moves through the environment. Reservoirs reduce the mass load of total mercury that would otherwise be available to move downstream by allowing mercury adsorbed to suspended sediment to settle. However, conditions of low dissolved oxygen promote the methylation of some portion of the trapped total mercury, which can result in locally elevated fish tissue levels.

- **What factors affect ambient methylmercury concentrations, bioaccumulation and biomagnification?** Research results in the SRW, Delta and elsewhere indicates that mercury methylation rates vary depending on several environmental factors, but are typically enhanced in wetland environments. Bioaccumulation processes depend on the amount of mercury in surficial sediments, the water quality at the sediment/water interface, and local food web dynamics. The functional relationships among these factors in the SRW are a topic of ongoing research.
- **What reduction in risk to humans and wildlife is produced by decreases in fish tissue levels for a given fish species?** Reducing risk of mercury requires knowledge of the relationship between risk and fish tissue concentration, which in turn requires knowledge of the amounts of certain fish species consumed by sensitive humans and wildlife. This question highlights an existing knowledge gap.
- **What level of certainty is there in quantifying the linkages between a remediation project (source reduction or bioaccumulation reduction) and fish tissue decreases?** Uncertainties in expected effects increase the farther the point of analysis is from the sources, with significant unknowns regarding aggregate effects of multiple source reductions, mercury transport and transformation, and bioaccumulation. Uncertainties regarding risk result from the lack of knowledge regarding fish consumption patterns and inherent uncertainties in the evaluation of effect thresholds. Because of the uncertainties in these important contributing factors, certainty in the overall linkage analysis is currently low. A survey of mercury remediation projects elsewhere indicates only moderate potential for success. Mercury source control efforts documented elsewhere have proven effective at reducing loads and fish tissue concentrations in severe loading situations. However, these efforts have not reduced fish tissue concentrations below the 0.3-mg/kg target level. Models for representing quantifiable elements and linkages are available but have not been employed to date in the SRW due to various limitations.

In the course of answering the preceding two fundamental questions, these knowledge gaps were identified:

Element	Description	Knowledge Gaps
1	Mercury sources to the environment	○ Atmospheric deposition rates and sources ○ Native soil content ○ Loads from mineral springs ○ Disposition of gold and mercury mine tailings ○ Effectiveness of source reductions
↓ *Linkage:*	*Natural and managed processes regulating mercury mass loading to aquatic systems near mercury sources*	
2	Mercury in water near sources	
↓ *Linkage:*	*Physical, chemical and biological transport, transformation, and entrapment processes on total mercury in the aquatic system during transport from sources to areas of methylation and biological uptake of methylmercury into food webs supporting target species*	○ Methylmercury loading rates from tributaries ○ Loads from Putah Creek and agricultural drains ○ Reservoir effects on transport ○ Effectiveness of site remediation
3	Ambient total mercury and methylmercury in water and sediment at locations where biomagnification to fish species of concern occurs	○ Relative bioavailability of source types

Element	Description	Knowledge Gaps
↓ *Linkage:*	*Biomagnification into target species as a function of ambient mercury concentrations in water and sediment and entry of methylmercury into food webs supporting target species*	○ Water quality factors affecting methylation, bioaccumulation, and biomagnification rates
4	Mercury in fish tissue	○ Data for Cottonwood and Thomes Creeks, many Sierra reservoirs
↓ *Linkage:*	*Exposure to humans and wildlife from consuming fish*	○ Food chain relationships ○ Fish consumption patterns by humans and wildlife
5	Risk to fish consumers (human populations and sensitive wildlife) due to methylmercury in fish tissue	○ Exposure levels and demonstrated effects of mercury in humans and wildlife

The remainder of this Plan recommends actions both to reduce mercury risk now and to address these knowledge gaps through additional study.

❑ Fundamental Question #3: What is a prudent course of action to reduce mercury risk in the SRW?

This question leads to the heart of the Plan, laid out in categories of recommendations:

- **Identify appropriate areas for and types of pilot remediation projects:** 1) facilitate and enhance programs to collect and dispose of elemental mercury collected in gold mining regions, 2) address legal liability issues for site remediation on a project-specific basis, 3) evaluate and characterize planned site remediation projects sufficiently to determine costs and effectiveness of the remediation, and 4) continue to develop the Decision Support Tool as information becomes available from ongoing monitoring and research activities to prioritize areas suitable for remediation.
- **Develop a modeling framework for incorporating quantified relationships, assessing monitoring data, and improving predictive ability:** 1) use multivariate regression analysis to prioritize factors affecting methylation and bioaccumulation, 2) simulate potential effects of remediation at Clear Lake, 3) focus watershed modeling in a tributary to the Sacramento River in collaboration with remediation activities, and 4) use a statistical bioaccumulation model as a first step in applying results of the watershed model to predict effects on biota.
- **Design and implement monitoring to assess local and regional effects of pilot projects and to support models:** 1) monitor total, methyl and inorganic mercury in water and sediment, and methylmercury in fish tissue for a long-term period (decades) at integrator sites where fishing intensity is high, and 2) monitor the effectiveness of source control and other environmental manipulations.
- **Design and perform research projects to reduce uncertainties in the linkage analysis and to improve models, and stay informed of and coordinate with other ongoing research projects in the areas of:**
    - *Source Loadings:* 1) monitor wet and dry atmospheric deposition of mercury monthly in major depositional zones of the SRW, 2) collect soil samples from Central Valley and tributary watersheds with higher than average mercury:total suspended solids ratios, 3) measure in-stream, reservoir, and riparian sediments, and 4) measure total and dissolved mercury concentrations and other water quality parameters in waters emanating from representative mineral springs.

  - *Methylation and Bioaccumulation:* 1) quantify mercury mass fluxes through wetland environments as a function of environmental conditions, and 2) study food web characteristics and interactions in Cache and Putah Creeks and in the San Francisco Bay Delta (“Delta”).
  - *Risk Assessment:* 1) conduct a fish consumption study to identify sensitive and highly exposed populations, 2) continue to monitor local avian species exposure to mercury through random egg collections, nest box studies, and egg exposure (reproductive failure) assessments, and 3) conduct a Margin of Exposure (MOE) analysis of mercury in hair of women of child-bearing age in the SRW.

- **Develop and implement an outreach program to collect additional fish consumption information and to inform and educate affected people regarding mercury risks in the short term.** 1) maintain and develop further the DTMC web site to communicate appropriate and balanced information regarding fish consumption advisories in waterbodies already designated, 2) work with other agencies as they develop mercury strategies, 3) finalize an outreach strategy based on the existing outline and find funding to implement it including the work on scoping the design of a fish consumption for the watershed and Bay-Delta which contains several tasks for outreach and education, 4) periodically update the SRWP traveling exhibit with appropriate information, 5) develop additional outreach tools to communicate the findings of the Strategic Plan and educate the public on mercury risks, 6) connect monitoring, research, and project implementation needs with funding agencies, and 7) inform the federal legislation process.
- **Continuously plan and evaluate progress:** 1) continue to use the USEPA criterion as the numeric fish tissue target for the SRW and Delta until better information is developed, 2) seek funding to maintain activity of the DTMC, and 3) participate in offsets program discussions to develop a format for evaluating projects.

Introduction

Water quality and biotic monitoring in Central Valley rivers and reservoirs and in the San Francisco Bay-Delta (“Delta”) reveals mercury contamination from natural soils and mineral springs, historic mining, atmospheric deposition, and other smaller sources, including urban inputs. This contamination has led to elevated mercury concentrations in fish tissue, posing a risk to human and wildlife fish consumers.

This document describes the key elements of a Strategic Plan (“Plan”) for the Sacramento River watershed (SRW) (Map 1). The objective of the Plan is to reduce the accumulation of mercury by fish through control actions within specific areas of the SRW. Many of the recommendations are related to pilot projects and studies that are specific and limited in area. Field studies will need to document that controls are effective at reducing mercury risk below target levels because no field studies to date have shown that controls are effective enough to reduce fish tissue concentrations below the target level. After the pilot phase, potentially effective actions will be taken on a larger scale. Coincident with the development of this Plan, the California-Federal Bay-Delta Restoration Program (CALFED) has developed a strategic plan for mercury research in the Bay-Delta watershed. The focus of that process is to identify research needs with the goal of understanding mercury processes that could be impacted by wetland restoration. The two plans are inherently complementary because they both address data and knowledge gaps with the intent of informing management action. CALFED research data will inform many of the project and management actions that originate from the DTMC Strategic Plan’s objective.

To identify effective means for reducing mercury in fish flesh across this huge watershed, we need to understand the sources and distribution of mercury, and how and where it is chemically transformed making it available to enter. Given the complexities of mercury transport, transformation and uptake in the SRW aquatic system, it is recognized that our understanding is in its infancy. Ongoing efforts to improve this understanding are a combination of focused research, pilot projects, and effectiveness monitoring. This planning effort establishes a rational framework for these activities.

To characterize the mercury issues and to lay out a course of action for dealing with those issues, this document addresses the following fundamental questions:

- ❑ What is the nature and extent of the human health and ecological risks caused by mercury in the SRW and downstream waters?
- ❑ How well understood is the nature of mercury risk and the ability to reduce it?
- ❑ What is a prudent course of action to reduce mercury risk in the SRW?

*The **objective** of this Strategic Plan is to reduce the accumulation of mercury by fish through control actions within specific areas of the SRW. Many of the recommendations are related to pilot projects and studies that are specific and limited in area because field studies will need to document that controls are effective at reducing mercury risk below target levels. After the pilot phase, potentially effective actions will be taken on a larger scale.*

*The **fundamental questions** addressed are:*
- *What is the nature and extent of the human health and ecological risks caused by mercury in the SRW and downstream waters?*
- *How well understood is the nature of mercury risk and the ability to reduce it?*
- *What is a prudent course of action to reduce mercury risk in the SRW?*

These questions are addressed in this Plan through the fundamental problem-solving approach depicted in Figure 1. The three inter-related elements – problem definition/evaluation, information gathering, and recommended actions – guide the development of this Plan. After describing our present understanding of the problem (in response to Question #1) and our ability to address it today (in response to Question

#2), this Plan recommends a course of actions that (a) attempts to reduce mercury risk by reducing fish tissue concentrations to the target level, (b) continues to develop information regarding the ability to reach the target level and the time frame for such tissue level change, and (c) informs the general public about the mercury issues (in response to Question #3).

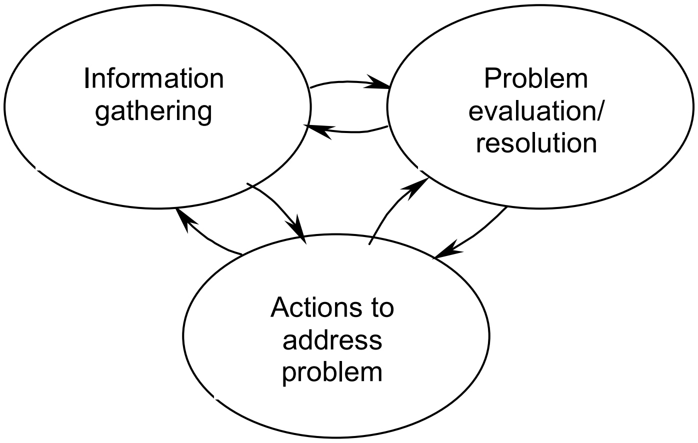

Figure 1. Basic elements of the strategic planning process. The three interconnected elements form the framework for this document.

This Plan has been developed by a diverse group of stakeholders comprising the Delta Tributaries Mercury Council (DTMC)[1]. The DTMC has come together to understand mercury-related human health and ecological risks and to coordinate efforts to establish a long-term plan to effectively reduce those risks. The DTMC is currently supported by the Sacramento River Watershed Program (SRWP), which has the goal of providing dependable and accessible information about the watershed through scientifically sound monitoring. The SRWP has conducted monitoring in the SRW since 1997, and has sought to coordinate its monitoring efforts with those of other groups working in the watershed (e.g., USGS NAWQA, Sacramento Coordinated Monitoring Program, City of Redding NPDES Monitoring, and Department of Water Resources' intensive tributary monitoring program).

This Plan supports the goals of the DTMC and the broader goals of the SRWP. The DTMC strategic planning process is focused on providing answers based on best available information to the aforementioned questions in the development of an implementation plan for the SRW. It is expected that this Plan will be useful to regulators, researchers, planners, the regulated community, and fund managers. The process used to generate this Plan and, to some extent, the recommendations contained within this report, are generally applicable to the larger Sacramento-San Joaquin Delta and tributary rivers (San Joaquin, Cosumnes, Mokelumne), although it focuses on the SRW, the Delta's major tributary area.

The Sacramento River Watershed

The 26,000 square miles (15 million acres) SRW consists of a major valley (Sacramento Valley) bounded by several mountain ranges: the Coast Range to the west, the Cascade and Klamath Ranges to the north and the Sierra Nevada Mountains to the east (see Map 1). Mineral springs are present in both the Cascade and Coast Ranges.

At its downstream end, the Sacramento River drains into the Sacramento-San Joaquin Rivers' Delta, a series of interconnected channels and sloughs that comprise the tidally-influenced, brackish water element of the San Francisco Estuary. Flows through the Delta mix with waters of San Francisco Bay and pass on to the Pacific Ocean under the Golden Gate Bridge. The Sacramento River connects along the

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[1] The DTMC's web page is found at http://www.sacriver.org/subcommittees/DTMC.

northern portion of the Delta and comprises the major freshwater input to the San Francisco Estuary. Other major rivers contributing flows to the estuary include the Cosumnes, Mokelumne, and San Joaquin Rivers, which connect to the Delta from the east and south.

The Sacramento River is the largest river in California, with an annual average stream flow volume of 22 million acre-feet (27 km^3/yr)[2]. The river is also the longest in the State, extending over 327 miles (526 km). Major tributaries to the Sacramento River include the Feather River, the American River, and the Pit River. Dams have been constructed over the past century[3] on the Sacramento River downstream of the confluence with the Pit River (Shasta Dam) and on each of the other major tributaries (Oroville Dam on the Feather River and Folsom Dam on the American River). In total, there are over one thousand lakes and reservoirs throughout the watershed. River diversions are also common for transferring water to users and for flood control in the Central Valley.

The Sacramento River and several tributaries support beneficial uses potentially impacted by mercury. These include aquatic life and wildlife habitat; sport, subsistence, and commercial fishing; and rare and endangered species habitat.

Predominant land uses in the SRW today are forests and rangeland, comprising 59% and 17% of the land area, respectively (Map 2). This figure illustrates the large area (much of it forested and at higher elevations) owned by federal and state agencies (37% and 2%, respectively), where land management practices could be addressed by specific remediation activities. Agricultural uses (predominantly rice in poorly drained clayey soils, along with orchards, field crops, and vineyards) comprise approximately 17% of the land area and are located primarily in the floor of the Sacramento Valley. There are about 2.5 million people living in the watershed, with over half of the urbanized population located at the downstream end in Yolo, Placer, and Sacramento Counties.

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The watershed was the site of significant mining activity during the 19th century, including hard rock and hydraulic gold mining (primarily in the Sierra Nevada), mercury mining in the Coast Range (primarily to support gold mining), and hard rock mining for copper, silver, and other metals in portions of the Sierras and northern Coast Range. California's Coast Range represents one of the world's five major mercury-mining areas (Jasinski, 1995). The enormous environmental damage caused by hydraulic gold mining instigated, in 1884, the first major federal court decree ever to be issued aimed at protecting a natural environment from further destruction (Kelley, 1989). By 1900, all major hydraulic mining had ceased. The legacy of these activities is elevated amounts of mercury in the soils, streams, and reservoirs over vast areas of the watershed. Current metal mining activity is predominantly small-scale gold mining and hobby suction dredging, although larger operations do exist. Mercury is no longer mined or used for processing gold in the SRW.

A limited long-term dataset from the Toxic Substances Monitoring Program, combined with more recent monitoring by the SRWP, exists to indicate trends in mercury levels in specific fish species at various locations in the SRW over the last 25 years (Figure 2). The overall picture is that there is no temporal trend in mercury in fish tissue over recent years[4]. This finding is consistent with effects expected from relatively constant inputs (being some combination of legacy and ongoing sources). Given that large-scale use of mercury in the watershed ceased nearly one century ago, there is no indication from these data that mercury levels in fish or water will change significantly without some form of intervention.

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[2] An acre-foot of water is enough water to fill an area of one acre to a depth of one foot.

[3] Note that the major dams were constructed after the hydraulic gold mining operations ceased, and that large volumes of the mining debris (discussed later in this section) washed farther downstream than the current dam locations.

[4] Data from the Feather River (the one site with a statistically significant trend) would show no temporal trend without the two most recent samples by the SRWP.

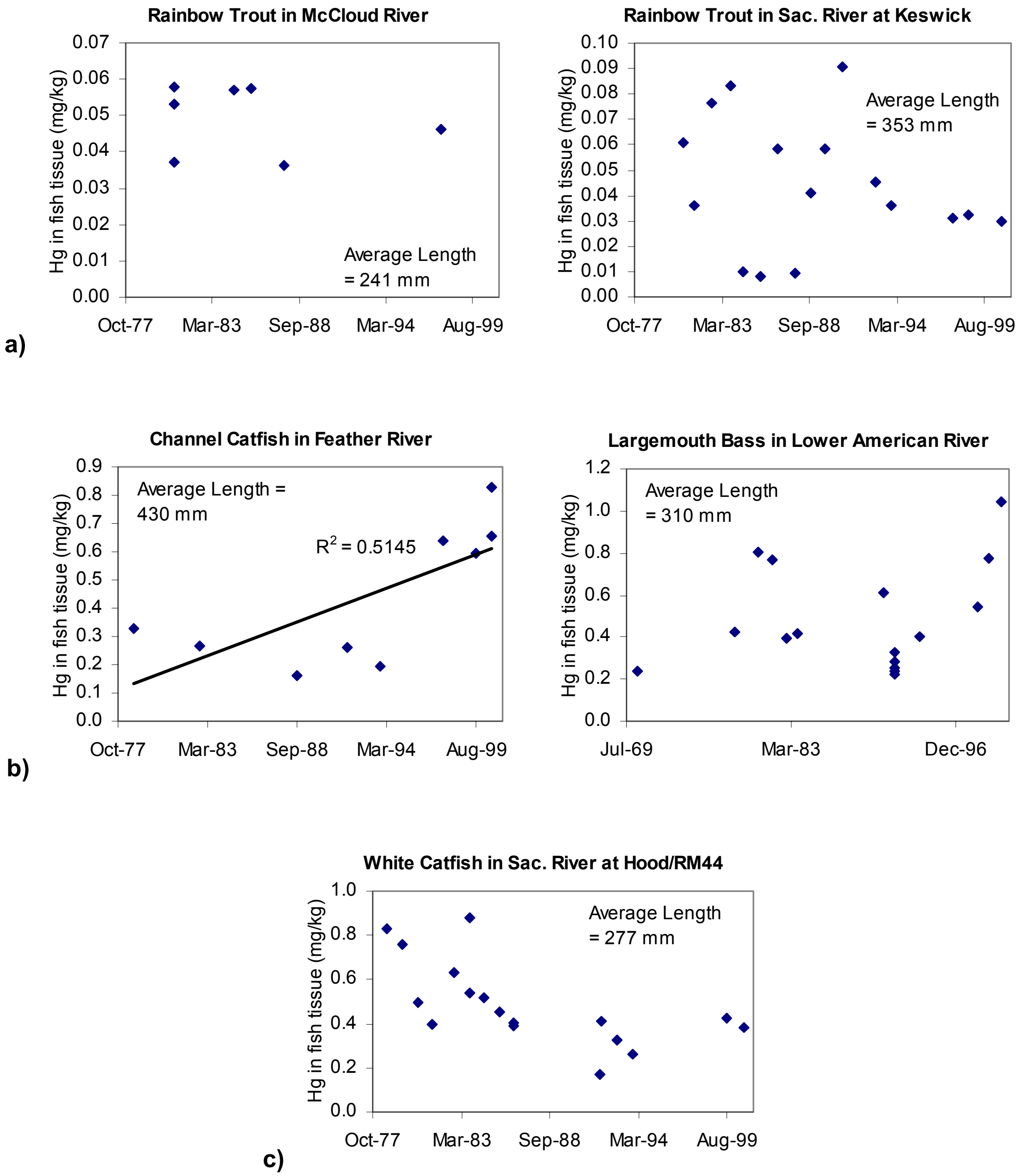

Figure 2. Mercury (Hg) concentrations in fish tissue (wet weight), 1970-2000, in a) the upper watershed, b) major tributaries of the Sierras, and c) the lower mainstem below Sacramento. Data come from the Toxic Substances Monitoring Program for years 1978-1994, and from the SRWP for years 1997-2000. The one data point for 1970 in the American River comes from the California Interagency Committee on Environmental Mercury (1971). Concentrations have been normalized to the average length (measured as total length) fish of each species at each site. Only the linear regression for Feather River data was significant ($p<0.05$). The waterways are shown in Map 1.

Conceptual Model

The conceptual model for mercury behavior in the SRW is shown in Figure 3 and described in the Mercury Conceptual Model Report (Appendix 1). The conceptual model describes source types, transport mechanisms, mercury speciation, transformation reactions in water and sediment, and mercury bioaccumulation. The conceptual model is used to depict the complex behavior of mercury as it moves from various sources into each environmental compartment (air, water, land, and biota), transforms into methylmercury, and accumulates in organisms.

In the evaluation of source types, it is commonly held that atmospheric sources are global, regional (e.g., Bay area and Central Valley), and local in scale. Watershed runoff and other non-point sources include several categories, such as urban stormwater, mine sites, mineral springs, and agricultural runoff. Point sources are outfalls from industrial discharges, treated wastewater, and urban runoff, although many sources assessed on a large scale as diffuse could be assessed on a small scale as point sources.

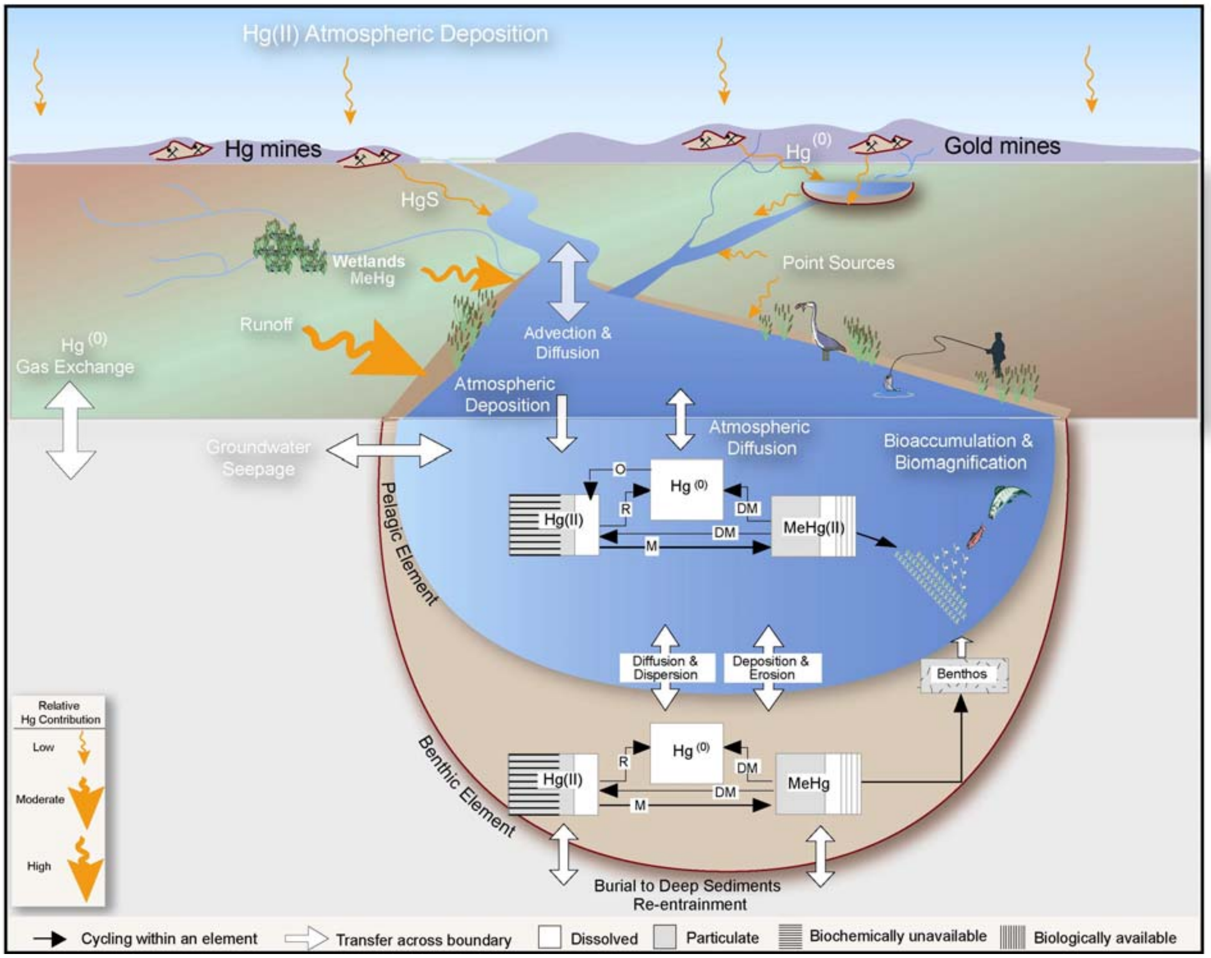

Figure 3. Mercury conceptual model for the SRW. The conceptual model report (Appendix 1) describes each of these model elements and their linkages. (O = oxidation, R = reduction, M = methylation, DM = demethylation, Hg^0 = elemental mercury, HgII = ionic mercury, MeHg = methylmercury)

As depicted in Figure 3, mercury exists in several different chemical forms in the environment. The important mercury[5] compounds can be separated into four categories based on lability (or reactivity) and bioavailability:

- ❑ Divalent mercury (HgII) – Most readily methylated, adsorbs to solids, highest proportion of wet and dry atmospheric deposition occurs in this form;
- ❑ Methylmercury (CH_3Hg^+ or "MeHg") – A form of divalent mercury, soluble in water, most readily biomagnifies, adsorbs to solids, highly toxic to humans and wildlife, generally low concentrations relative to other forms but can be high under anoxic conditions;
- ❑ Elemental mercury (Hg^0), also referred to as "quicksilver" – Liquid at room temperature but highly volatile (most prevalent form fluxing into atmosphere), dissolves little into water, oxidizes to HgII in sunlight, found in mercury and gold mining areas, most prevalent form in atmosphere (>95%); and
- ❑ Cinnabar (HgS), also referred to as "inert" or "inorganic" mercury – Solid, non-reactive, and relatively unavailable and non-toxic to biota, found in natural ores and sediments and in mercury mining waste piles.

The terms "mercury" and "total mercury" are used in this Plan to represent all forms of the element. Monitoring and analyses of mercury are encumbered by wide range of values to relate. For example, if all suspended material could be removed from the water entering the Delta from the Sacramento River and hauled away in large-haul trucks, it would require 82,000 *truckloads* each year to do so. If the mercury bound to that sediment could be removed entirely from the water passing by and consolidated into two-liter bottles, it would fill up just 14 bottles in an average year. Yet three million fish with 0.3 mg/kg of mercury in their tissue constitute less than one-twentieth of one bottle.

The following reactions are most prevalent in the mercury cycle:

- ❑ *Reduction* – Divalent mercury or cinnabar reduces in the aquatic environment to elemental mercury. Cinnabar reduces to elemental mercury when heated, as was commonly done at mercury mine sites. The reduction process is much slower in water than in air.
- ❑ *Oxidation* – Elemental mercury (Hg0) is oxidized to divalent mercury (HgII). The reaction is enhanced by sunlight and ozone in air.
- ❑ *Methylation* – Divalent mercury (HgII) adds a methyl group to become methylmercury (MeHg). The process of methylation is thought to be primarily a biological process involving sulfate-reducing bacteria (Gilmour et al., 1992). Methylation typically occurs in sediment, but also may occur in overlying water (Rudd et al., 1983).
- ❑ *Demethylation* – Methylmercury releases its methyl group and becomes another form of divalent mercury, by bacteria as well as by sunlight ("photodegradation").
- ❑ *Sorption/desorption* – Divalent mercury (including methylmercury) adsorbs to and desorbs from particulate material in water, particularly colloidal and smaller particles.

The rates of these reactions vary considerably, depending on numerous factors, on time scales ranging from hourly to seasonally (Krabbenhoft et al., 1998). But the most important reaction, methylation, appears to be very fast, on the order of hours.

Useful Definitions

Bioavailable *– any form of a contaminant that is readily incorporated into biota.*
Bioaccumulation – *the process of accumulating a bioavailable contaminant faster than it is released.*
Biomagnification – *The phenomenon of increased concentrations of a contaminant with increasing trophic levels in a food web.*

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[5] Note that the chemical symbol for mercury "Hg" is often used as short-hand.

Fundamental Question 1 – What is the nature and extent of the human health and ecological risks caused by mercury in the SRW and downstream waters?

The answer to this overall question, aimed at understanding the problem, is addressed in two parts.

Question 1a – What are the existing health risks of mercury to humans and wildlife in the SRW?

Answer – Methylmercury is the most toxic and bioaccumulative form of mercury. According to US Environmental Protection Agency (USEPA), pregnant women eating more than 17.5 g/day (0.6 oz/day) of fish with 0.3 mg or more of methylmercury per kg of fish tissue (mg/kg) have an increased probability that adverse effects may be observed in their unborn children. Health risks to wildlife are species-specific and largely unknown. The mercury risk to fish-consuming wildlife in the SRW is presumably dependent on fish consumption rates and mercury levels in major prey species. Since there is no definitive information available on feeding habits or consumption rates, it is not possible to make meaningful statements regarding the risk to wildlife.

At specific dosages and exposures, methylmercury in humans has been found to affect the immune system, alter genetic and enzyme systems, and damage the nervous system, including coordination and the senses of touch, taste, and sight. The nervous system appears to be most susceptible to mercury effects, and is the only likely effect to be observed at the mercury concentrations in fish of the SRW. Fish are affected by mercury at concentrations over ten times higher than those found to impact humans and wildlife and are typically not affected at concentrations observed in most aquatic systems (Wiener and Spry, 1996).

California Office of Environmental Health Hazard Assessment (OEHHA)
Fish Consumption Recommendations

1. *Eating sport fish in amounts slightly greater than what is recommended should not present a health hazard if only done occasionally.*
2. *Nursing and pregnant women and young children may be more sensitive to the harmful effects of some of the chemicals and should be particularly careful about following the advisories.*
3. *The limits for each species and area assume that no other contaminated fish is being eaten.*
4. *Just because the area where you like to fish is not included in the specific advisory areas that follow, it does not necessarily mean that it is free from chemical contamination*

The most significant pathway for human and wildlife exposure to methylmercury is through the consumption of mercury-laden fish or shellfish. The most direct measures of health risks to humans and/or fish-eating wildlife are mercury concentrations in the exposed populations. It is difficult to prove cause and effect in field studies, however, because other factors that may contribute to the biological effect under study (for example, reproductive success) are often impossible to control.

A lack of data regarding exposure levels and demonstrated effects of mercury in humans and wildlife in the SRW poses uncertainty. In one study at Clear Lake (the only location extensively surveyed), observed mercury concentrations in humans (i.e., blood and hair) and wildlife (i.e., brain, liver, kidney, and feather) were below threshold levels (30 ug/L) shown to have adverse effects in laboratory studies (see Appendix 2). A correlation between fish consumption and blood organic mercury level was observed. Blood levels within the Native American community showed that 20% exceeded 20 ug/L and 100% exceeded 3 ug/L. Although these data indicate that a minimal 10-fold margin between adverse effect levels and observed levels is not being maintained, no person sampled exceeded the threshold level.

In lieu of these more direct measurements, tissue levels in fish and shellfish, coupled with consumption rates, are typically used to approximate risk. Mercury levels in tissue of certain fish species in the SRW and Delta exceed levels that may pose a health concern to sensitive populations that consume significant levels of those species. These levels include the fish tissue criterion (0.3 mg/kg wet weight) and other human health-based "action levels" recently recommended by the USEPA (2001b). The segment of the human population believed to be at greatest risk is unborn children of women consuming more than 17.5 grams per day (g/day)[6] of fish with mercury concentrations in their tissue exceeding the criterion. This standard is based on risk to the 90th percentile of exposed women and has an additional safety factor of 10.

The consumption rate of 17.5 g/day is equivalent to 2.3 meals per month, based on an 8-oz portion of fish at each meal (a typical assumption). Therefore, the current USEPA criterion would indicate that a pregnant woman could eat 2.3 meals per month of a fish with 0.3 mg mercury/kg in its tissue. The problem with using the California Office of Environmental Health Hazards Assessment (COEHHA) advisory in this discussion is that the fish tissue concentration used for the advisory is unstated. To make the two approaches consistent, the fish tissue level in striped bass of the size assumed by COEHHA would have to have been 0.69 mg/kg (0.3 mg/kg * 2.3 meals/month) to equate to a one meal per month recommendation.

The Central Valley Regional Water Quality Control Board (RWQCB) has listed[7] several waterbodies in the SRW as exceeding water quality standards for mercury, based on measured fish tissue concentrations (Map 3). Proposed[8] additions to the 2002 list for the SRW include Bear Creek, Upper Bear River, Black Butte Reservoir, Camp Far West Reservoir, Combie Reservoir, Englebright Reservoir, Little Deer Creek, Lower Putah Creek, Rollins Reservoir, and Scotts Flat Reservoir. These additions to the list are due to new data, not because of increasing levels of contamination. This list represents the present, high-priority concern for impacts of mercury in the SRW. Mercury levels in fish have raised concerns on a global scale. Nationally, 79% of all fish advisories in the US, found in 41 different states, are because of methylmercury contamination (USEPA, 2001a).

Data collected over the period from 1997 through 2000 under the SRWP provide a current estimate of average mercury concentrations in fish consumed by local fishers (Table 1). These estimates are based on actual fish tissue measurements and USEPA default fish consumption rates (described under Question 1b). Trophic levels relate to the positions of fish in the food chain (e.g., a minnow would be Trophic Level 2, a bass would be Trophic Level 4). Consumption rates of trophic level 2 (TL2) fish appear to be lower in this watershed than the standard assumptions would indicate; therefore the consumption rate of TL2 fish is proportioned into TL3 and TL4 fish. Largemouth and striped bass, channel and white catfish, and pike minnow are the species that tend to have mercury levels above the criterion. All are resident species (territorial rather than migratory) and thus serve fairly well as indicators of conditions at the location where the fish were caught. The objective of fish monitoring has been to identify areas where fish tissue mercury concentrations exceeded criteria, rather than to identify spatial trends. Nonetheless, it appears that lower reaches of the major tributaries (Feather and American Rivers) are of concern (i.e., concentrations in fish tissue exceed the 0.3 mg/kg weighted average value), followed by Central Valley agricultural drains. Fish tissue levels in Cottonwood and Thomes Creeks and many reservoirs in the Sierras with potential contamination have not been monitored. More information on mercury concentrations measured in water and biota of the SRW can be found in the SRWP's Annual Monitoring Report (SRWP, 2002).

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[6] 17.5 grams is approximately 0.6 ounces; 17.5 g/day is approximately 1.1 pounds/month or two meals per month.

[7] The list is referred to as the "303(d) list" because of the legal code requiring it.

[8] Staff recommendations for changes to the 303(d) list were transmitted to the SWRCB in April 2002. The proposed list for the Central Valley is available at www.swrcb.ca.gov/rwqcb5/programs/tmdl/index.htm.

Table 1. Estimates of Consumption-weighted average fish tissue mercury concentrations at various locations in the SRW (1997-2000).

				Hg concentrations in fish tissue, mg/kg, wet weight			
Waterbody Type	Species	Trophic Level(1)	Count	Mean	Std. Dev.	Species-weighted trophic level avg(2)	Consumption-weighted avg(3)
Ag drains (Sacramento Slough, Colusa Drain, Natomas East Main Drain)	Carp	3	2	0.14	0.052	0.14	0.33
	Largemouth bass	4	6	0.56	0.096	0.58	
	Striped bass	4	1	0.81	•		
	White catfish	4	7	0.36	0.155		
Tributaries (Sac. R. above Shasta, Pit River, McCloud River, Clear Ck, Mill Ck, Deer Ck, Big Chico Ck, Putah Ck,)	Bluegill	3	6	0.12	0.037	0.11	0.20
	Brown trout	3	1	0.06	•		
	Rainbow trout	3	9	0.05	0.007		
	Riffle sculpin	3	9	0.16	0.098		
	Sacramento sucker	3	1	0.19	•		
	Largemouth bass	4	19	0.43	0.178	0.30	
	Pikeminnow	4	1	0.48	•		
	Smallmouth bass	4	2	0.15	0.11		
	White catfish	4	1	0.15	•		
Major tributaries (Feather River and American River)	Bluegill	3	1	0.12	•	0.18	0.48
	Redear sunfish	3	2	0.26	0.058		
	Sacramento sucker	3	3	0.14	0.09		
	Channel catfish	4	1	0.73	•	0.88	
	Largemouth bass	4	33	0.84	0.484		
	Pikeminnow	4	6	0.60	0.303		
	Striped bass	4	5	1.60	1.172		
	White catfish	4	12	0.65	0.314		
Lower Sac. R. Mainstem (Keswick to "I" Street Bridge)	Carp	3	1	0.19	•	0.10	0.25
	Rainbow trout	3	5	0.04	0.004		
	Sacramento sucker	3	4	0.07	0.034		
	Largemouth bass	4	2	0.89	0.099	0.45	
	Pike minnow	4	6	0.22	0.074		
	Striped bass	4	1	0.30	•		
	White catfish	4	2	0.38	0.239		
Delta (Sac. River below "I" Street Bridge, and Cache Slough)	Bluegill	3	1	0.10	•	0.12	0.25
	Carp	3	1	0.11	•		
	Sacramento sucker	3	2	0.16	0.081		
	Crappie	4	1	0.32	•	0.40	
	Largemouth bass	4	45	0.80	0.305		
	Pikeminnow	4	1	0.12	•		
	Striped bass	4	1	0.34	•		
	White catfish	4	51	0.44	0.224		

(1) Trophic level 3 fish consume primarily zooplankton and benthic invertebrates. Trophic level 4 fish preferentially consume trophic level 3 and lower trophic level fish species, as well as benthic invertebrates. Larger individuals of some primarily trophic level 3 species (e.g. trout) may be piscivorous and function at trophic level 4.

(2) The average mercury concentration for each trophic level, calculated as the average of mercury concentrations for each species in the trophic level.

(3) The average mercury concentration for total freshwater and estuarine fish consumed, as described in the Total Maximum Daily Load (TMDL) for Total Mercury in Fish Tissue Residue in Lake Bennett (USEPA 2001b). The consumption-weighted average is calculated as: Consumption-Weighted Average = (56.6% x Trophic Level 3 avg.) + (43.4% x Trophic Level 4 avg.).

Mercury levels in avian eggs taken from Suisun and San Francisco Bay are high enough to put a third of the bird species sampled at potential risk of embryo mortality, assuming established thresholds in mallards and pheasants can be applied to other species. This assumption may be erroneous, however, because the range in concentrations causing toxicity among aquatic species is often three or four orders of magnitude[9]. Species at potential risk in Suisun and San Francisco Bay include Caspian Terns, Forster's Terns, Double-crested cormorants, California Clapper Rails, and snowy plovers[10]. Benthic foragers like plovers, stilts, and rails also accumulated significant amounts of mercury in eggs, indicating that the benthic food web can be a significant source of methylmercury for adult birds and their eggs in parts of the Bay-Delta System (Schwarzbach and Adelsbach, 2001).

Question 1b – What is an appropriate target level of mercury in fish?

Answer – USEPA recommends a target of an average of no more than 0.3 milligrams (mg) methylmercury per kilogram (kg) of fish tissue to avoid mercury risk in the human population. At this target level, there likely would be no observable adverse effects to children or adults if locally caught fish are consumed at a rate of <17.5 grams per day. Although this target level has been assumed to reduce risk to wildlife to an acceptable level, recent information may indicate otherwise.

The target mercury concentration selected by the Central Valley RWQCB for its mercury TMDL[11] in Clear Lake is based on fish tissue levels. The essential reasoning for setting targets based on fish tissue concentrations is that the links in the causal chain closer to sources (i.e., water or sediment levels) are not adequately correlated with fish tissue concentrations (discussed in response to Question 2c). A brief summary of the process to develop target mercury concentrations follows.

Target mercury levels in fish tissue protective of humans and wildlife are derived from the following formula:

$$Target\ \ Hg_{fish} = \frac{Maximum\ \ acceptable\ \ intake\ \ rate * Body\ \ weight}{Fish\ \ consumption\ \ rate}$$

Units for the fish tissue target methylmercury concentration are typically expressed in wet weight as milligrams per kilogram (mg/kg) or, the equivalent, micrograms per gram (μg/g).

Reference Doses

The USEPA reference dose (RfD) is a level 10 times below the estimated dose at which daily exposure (intake rate of mercury per kg of body weight) produces adverse effects in children. USEPA predicts that this RfD is likely to be without risk of adverse effects to human consumers when experienced over a lifetime (70 years). The California Toxics Rule (CTR) (2000) states "As frequency of exposures exceeding the RfD increases and as the size of the excess increases, the probability increases that adverse effect may be observed in a human population".

Target Mercury Levels for Humans

The DTMC Mercury Targets Report (Appendix 2) identifies a range of candidate fish tissue targets, based on human health concerns. The range (from 0.2 to 0.6 mg/kg wet weight) depends on the selected

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[9] This toxicity range is being studied by USFWS for CALFED.

[10] The later two species are federally protected endangered species.

[11] "TMDL" stands for Total Maximum Daily Load, a program and process to express the maximum amount of a pollutant that a water body can receive over some time period and still attain water quality standards, and then an allocation for load reductions among point and diffuse sources of that pollutant. The complete report for Clear Lake is available at: http://www.swrcb.ca.gov/rwqcb5/programs/tmdl/clearlake.html.

acceptable intake rate and the *assumed fish consumption rate*. The acceptable intake rate is based on the risk related to the estimated certainty of avoiding adverse effects in sensitive populations. The consumption rate is an estimate of the amount of locally caught fish that members of the public are expected to catch and consume.

The USEPA national mercury fish tissue criterion adopted in January 2001 (0.3 mg MeHg/kg wet weight) falls in the range of the candidate targets identified in Appendix 2. The USEPA fish tissue criterion was calculated based on the following assumptions:

> 1. Assumed *acceptable intake rate* used for the USEPA criterion is the USEPA reference dose (RfD) of (0.1 μg/kg/day) less an estimated intake rate from other sources (e.g., canned tuna and other foods) times an assumed adult body weight of 70 kg (154 pounds).
>
> 2. For the *assumed local fish consumption rate*, USEPA uses the 90th percentile rate in the general population for consumption of non-marine fish. This rate (17.5 g/day) was determined in a study performed by the US Department of Agriculture (USDA, 1998).

USEPA Mercury Fish Tissue Criterion Calculation

$$USEPA\ \ Fish\ \ Tissue\ \ Criterion = \frac{\left(RfD - Other\ \ Sources\right)\ \ x\ \ Body\ \ Weight}{Fish\ \ Consumption\ \ Rate}$$

$$= \frac{(0.1 - 0.027)\ \mu g/kg/day \times 70\ kg}{17.5\ g/day}$$

$$= 0.3\ \mu g/g\ (= 0.3\ mg/kg)\ wet\ weight$$

The approach used by USEPA Region 4 in Georgia to develop fish tissue criterion for several mercury TMDLs[12] provides a method by which attainment of the criterion can be judged. The method uses a trophic level-based, weighted average approach. The following default values are used as an assumption of human fish consumption rates by trophic level, unless better information is available[13]:

> Trophic Level 2 (TL2) = 3.8 g/day, TL3 = 8 g/day, TL4 = 5.7 g/day, for a total assumed consumption rate of 17.5 g/day.

The assignment of fixed trophic levels to individual fish species, while convenient, does not reflect the substantial spatial and temporal variation that can occur in the trophic position of a fish species. Even adult fish within a single population can vary substantially in trophic position. Local trophic level fish consumption rates by humans are largely unknown and represent an important data gap in the evaluation of risk.

Target Mercury Levels for Wildlife

Criteria for the protection of wildlife in other areas of the United States (e.g., Great Lakes) have been examined in detail (Appendix 2). However, understanding the risk to breeding piscivorous (fish-eating) birds and mammals (e.g., otters) requires site-specific information regarding feeding habits and food chain relationships. Fish consumption rates by various local wildlife populations are unknown.

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[12] See, for example, USEPA (2001c).

[13] USEPA encourages authorities to use local fish consumption data over defaults. A later recommendation is to collect fish consumption data in the SRW.

Fundamental Question 2 – How well understood is the nature of mercury risk and the ability to reduce it?

As a first step to understanding the nature of mercury risks and the ability to reduce it, the DTMC developed the conceptual model of mercury behavior in the environment (Figure 3, presented above). As a second step, connections and relationships described at the conceptual level between mercury sources, mercury fate in the environment, mercury concentrations in fish tissue, and mercury risks were framed in a linkage analysis. The linkage analysis helps identify knowledge gaps that need to be filled before the nature of mercury risks can be fully understood. The linkage analysis serves as a tool to assist in understanding opportunities for the control of mercury risk. The control measures noted here are described in more detail in Appendix 3.

Linkage Analysis

The first step is to define the elements that comprise the overall linkage (Figure 4):

Elements	Description
1	Mercury sources to the environment
↓ *Linkage:*	*Natural and managed processes regulating mercury mass loading to aquatic systems near mercury sources*
2	Mercury in water near sources
↓ *Linkage:*	*Physical, chemical and biological transport, transformation, and entrapment processes on total mercury in the aquatic system during transport from sources to areas of methylation and biological uptake of methylmercury into food webs supporting target species*
3	Ambient total mercury and methylmercury in water and sediment at locations where biomagnification to fish species of concern occurs
↓ *Linkage:*	*Biomagnification into target species as a function of ambient mercury concentrations in water and sediment and entry of methylmercury into food webs supporting target species*
4	Mercury in fish tissue
↓ *Linkage:*	*Exposure to humans and wildlife from consuming fish*
5	Risk to fish consumers (human populations and sensitive wildlife) due to methylmercury in fish tissue

Sub-questions raised and addressed in this section are derived from the linkage analysis:

☐ How effective is source control at reducing mercury concentrations in target species (Linkage 1→2)?

☐ How do fate and transport processes impact mercury concentrations in downstream locations (Linkage 2→3)?

☐ What factors affect ambient methylmercury concentrations and bioaccumulation (Linkage 3→4)?

☐ What reduction in risk to humans and wildlife is produced by decreases in fish tissue levels for a given fish species (Linkage 4→5)?

☐ What level of certainty is there in quantifying the linkage between a remediation project (source reduction or bioaccumulation reduction) and fish tissue decreases?

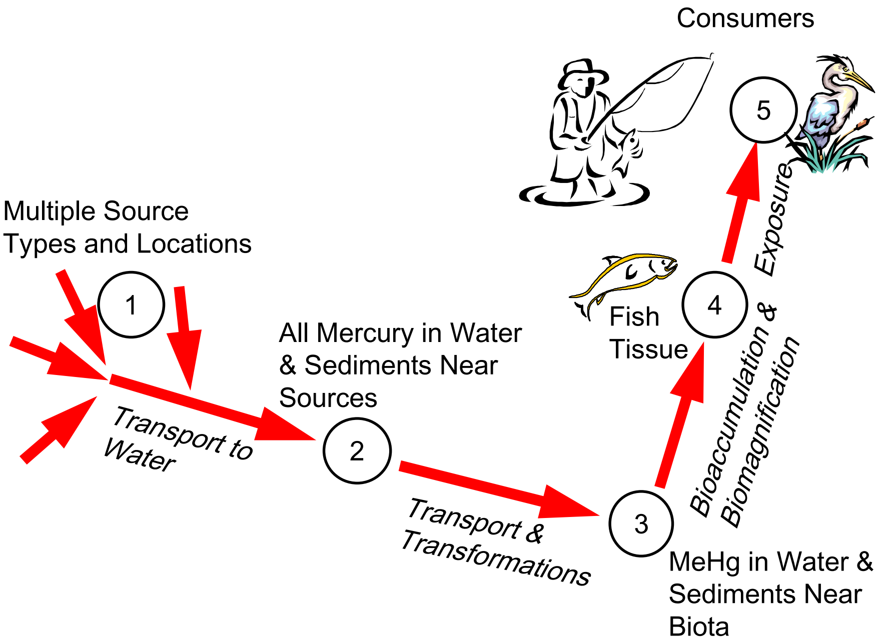

Figure 4. Linkages between mercury sources and risk to consumers. This linkage set is the framework for the questions related to our understanding of the problem.

Question 2a – How effective is source control at reducing mercury concentrations in target species (Linkage 1→2)?

Answer – In the SRW, source loadings are generally only grossly quantifiable. Source control effectiveness will be highly site-specific and dependent on sources' concentrations and relative contributions to levels in fish.

Mercury Sources (Element 1)

Major mercury deposits (in the form of cinnabar) exist along the west side of the SRW in the Coast Range. Numerous mercury mines were operated in this area in the second half of the 19th and first half of the 20th centuries, producing mercury used in gold recovery, weapons production, and consumer products. These mercury mine sites are now inactive. Mercury-enriched soils and mercury containing waste piles located around these sites are sources of cinnabar, elemental mercury, and other mercury species being leached and eroded into waterbodies in the SRW, and into the Delta.

Unlike other watersheds where mercury contamination can be traced to industrial uses such as chlor-alkali plants and pulp and paper mills (Ebinghaus et al., 1999), the anthropogenic contamination in the SRW was mainly due to mercury mining in the Coast Range or the use of major quantities of the elemental mercury produced in Coast Range mines used for gold recovery in the Sierra Nevada range prior to the 1920s. Mercury losses from those operations resulted in elevated concentrations that persist today in sediments, stream banks, tunnels, and reservoirs throughout these areas. Sediment erosion, evasion (released from plants and soil into the air), and groundwater movement have all contributed to the transport of mercury from contaminated sites, generally dispersing it over much larger areas. These and other natural and human-caused sources of mercury are described in Appendix 1.

Locally elevated mercury concentrations are observed in aquatic biota near point sources throughout the Sierra mother load (Slotton et al., 1997a) as well as in tributaries to Cache Creek in the Coast Range (Slotton et al., 1997b; Slotton and Ayers, 1999). Other waterways, such as Central Valley agricultural drains, lower reaches of the Feather River, much of the Putah Creek watershed, and the mainstem Cache Creek, exhibit relatively elevated mercury levels in sediment and biota over large areas, suggesting a more diffuse loading effect (Slotton et al., 1997a; J. Rytuba, presentation to DTMC, 11/19/02). Mercury mining activity in other watersheds, e.g. in Oregon (Park and Curtis, 1997) and in the Carson River watershed (Miller et al., 1998) as well as other regions worldwide (Ebinghaus et al., 1999), has been shown to increase bioaccumulation of mercury in fish tissue far downstream.

The SRWP, USGS NAWQA Program, Sacramento Coordinated Monitoring Program, City of Redding discharge permit monitoring, and California Department of Water Resources have monitored total and methylmercury concentrations in water throughout the SRW. Available mercury data for selected locations are presented in Table 2. Information from these monitoring efforts provides a basic characterization of the distribution of mercury loads by sub-watershed and source category. Monitoring stations for these programs are shown in Map 4. Total mercury loads in the SRW have been computed from monthly-averaged flow and concentration measurements from these stations[14]. Because of the limited number of monitoring sites with methylmercury data and because of methylmercury's non-conservative nature, similarly detailed mass load estimates for tributaries are not feasible at this time. Because flow and total suspended solids (TSS) co-vary and the flow dataset is longer and more comprehensive, flow is a more useful surrogate than TSS for estimating total mercury loads.

Map 5 presents mercury loads from major tributaries on a "per area" basis. This figure highlights areas with higher loadings *relative to their area*. The three watersheds with the highest mercury loads per area (highest "export coefficients") each have different major sources. These are Cache Creek (in the Coast Range, which has mineral springs and mercury mines), Mill Creek (in the Cascade Range, which has mineral springs) and the Feather River (in the Sierra Nevada Range, which has historic gold mines). Comparable data are lacking for Putah Creek, agricultural drains in the Central Valley, and several smaller tributaries.

Figure 5 illustrates total mercury loads from major tributaries and at various points along the mainstem of the Sacramento River. The impression gained from this figure is that although tributaries in the upper watershed (above Verona at river mile 80) are relatively insignificant compared to Sierra tributaries and Cache Creek, still approximately half of the load measured in the Sacramento River at Freeport (SRFPT) comes from the upper Sacramento, above Verona (SRVON).

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[14] Mass load in water is the mass of the material (mercury, in this case) that passes a point over a given time period, calculated as the product of its concentration in the water (mass per volume) and the water's flow rate (volume per time). See complete discussion of the mass load estimates in Appendix 1.

Table 2. Mercury sample stations within the SRW, 1993-2000. An "X" indicates that data are available for that constituent.

Station Name	Station Description	Flows	THg	MeHg	HgII	TSS	Biota	Fish
ARCNW	Arcade Creek at Norwood Ave.	X	X			X		
ARDPK	American River at Discovery Park	X	X			X	X	X
ARNIM	American River at Nimbus	X	X				X	
BATBR	Battle Creek at Bridge	X	X	X				
BEARC	Bear Creek near Anderson		X	X				
CCHCK	Cache Creek at Rumsey	X	X	X	X	X		
CCHSL	Cache Slough near Ryers Ferry		X			X		X
CCMOU	Clear Creek near Mouth	X	X	X				X
CHASH	Big Chico Creek above Salmon Hole	X	X			X		
CHCHI	Big Chico Creek at Chico (Rose Ave.)	X	X			X		
CHHWY	Big Chico Creek at Hwy 32	X	X			X		X
CHMUD	Big Chico Creek above Mud Creek	X	X	X		X		
COLDR	Colusa Basin Drain		X	X	X	X		X
COTCO	Cottonwood Creek near Cottonwood	X	X	X				
COWCR	Cow Creek near Millville	X	X	X				
DCMDW	Deer Creek below Childs Meadows	X	X			X		X
DCMOU	Deer Creek at Mouth	X	X			X		
DCPON	Deer Creek at Ponderosa Way	X	X			X		
DCUDD	Deer Creek at Upper Diversion Dam	X	X			X		
ELDER	Elder Creek at Gerber	X	X	X				
FRNIC	Feather River near Nicolaus	X	X			X	X	X
MCBLR	Mill Creek at Black Rock	X	X			X		X
MCHWY	Mill Creek at Highway 36	X	X			X		X
MCMOU	Mill Creek at Mouth	X	X	X		X		X
MUDCH	Mud Creek above Big Chico Creek		X			X		
REDBK	Red Bank Creek near Red Bluff		X	X				
SACSL	Sacramento Slough		X	X	X	X		X
SCKPP	Spring Creek Power Plant Discharge to Keswick Res.	X	X			X		
SRABB	Sacramento River above Bend Bridge	X	X	X		X		X
SRBKR	Sacramento River below Keswick	X	X	X		X		X
SRCOL	Sacramento River at Colusa	X	X	X	X	X		X(1)
SRFPT	Sacramento River at Freeport	X	X	X	X	X		
SRHAM	Sacramento River near Hamilton City	X	X	X		X		X(1)
SRRMF	Sacramento River at River Mile 44	X	X			X		X
SRVET	Sacramento River at Veterans Bridge	X	X			X		X
SRVON	Sacramento River at Verona	X	X	X	X	X		
SACSL	Stony Creek below Black Butte	X	X	X				
THMPA	Thomes Creek near Paskenta	X	X	X				
YOLOB	Yolo Bypass near Woodland	X	X					
YRMRY	Yuba River at Marysville	X	X			X		

(1) Insufficient data for use.

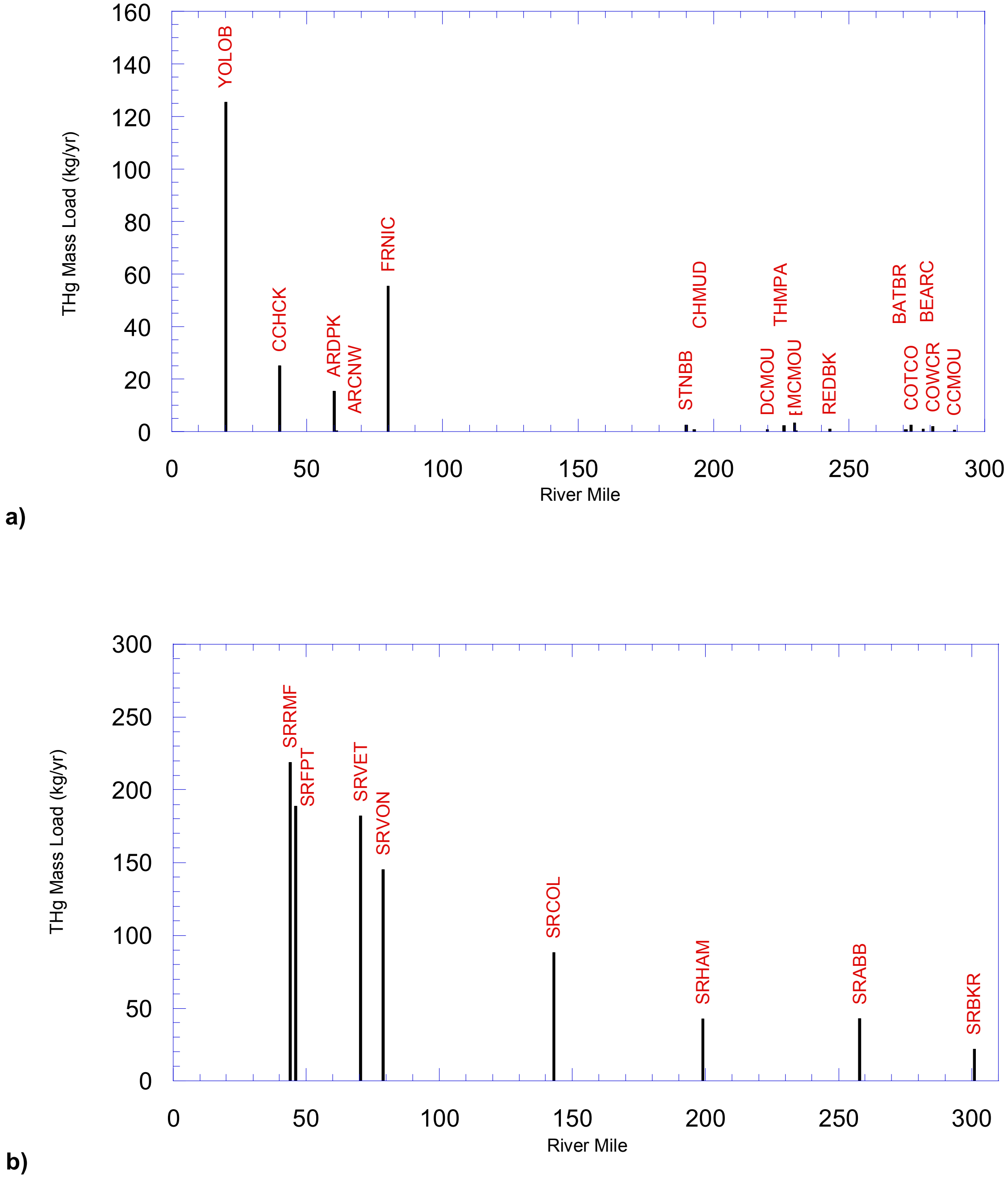

Figure 5. Estimated annual average mass loads for total mercury (THg) at selected stations in the SRW showing a) tributary stations and b) mainstem stations. River mile 0 is at the mouth of the Sacramento River in the Delta. Note that the vertical scales vary. Loads in the mainstem increase throughout its length. All stations are shown in Map 4 and described in Table 2.

Mercury leaving the SRW from various sources has been estimated based on independent measurements (if available) and assumptions (as necessary), and deduced from data at monitoring stations where only one additional major source is present[15]. The mass load estimates noted for each source type are for the Sacramento River at River Mile 44 plus the Yolo Bypass (sampled upstream of Putah Creek).

Mercury Sources in the SRW

Quantified mercury sources:

- *Atmospheric deposition*
- *Permitted discharges of treated wastewater*
- *Erosion of native sediment*
- *Urban runoff*
- *Discharges from naturally occurring mineral springs*
- *Erosion and leaching from inactive mercury mining sites*
- *Erosion and leaching from historic gold mining sites.*

Unquantified mercury sources:

- *Re-suspension of contaminated sediments.*
- *Erosion and leaching of pesticide residue in soils*
- *Releases from other mineral mines and waste disposal sites*

Loads computed based on independent measurements:

- ☐ *Atmospheric deposition (3 kg/yr)* – Historically, mercury production and gold recovery facilities were major sources of mercury releases to the atmosphere. Combustion of fuels containing mercury, evasion from terrestrial and aquatic sources and incineration of or direct volatilization from mercury containing wastes are the principal current sources of regional mercury emissions to the atmosphere today[16]. USEPA's RELMAP[17] model for wet and dry atmospheric deposition (Keating et al., 1997) provides the only estimate of atmospheric mercury deposition for the SRW. Results indicate that the total annual *deposition* of mercury in the SRW is 136 kg/year (300 lb/yr). This load onto the landscape is approximately equal to the total load of mercury measured in the Sacramento River at Freeport. The amount of deposited mercury that gets conveyed to waterbodies (~3 kg/yr) rather than sequestered or re-emitted is estimated based on land use data[18]. The annual deposition of mercury to the entire San Francisco Bay Estuary from both wet and dry deposition totaled 18.2 $\mu g/m^2$ in a recent study (Tsai and Hoenicke, 2001). RELMAP results predicted annual depositions of 3.2 $\mu g/m^2$ over that same area, six times lower than measured. Atmospheric deposition rates appear to have increased two to four times over the past century, as evident in lake sediment cores sampled in the Lake Tahoe basin (Heyvaert, 2000) and elsewhere worldwide (Wiener et al., 2002; Engstrom and Swain, 1997). Some air releases may be deposited in relatively close proximity to the emission source resulting in elevated soil and aquatic concentrations and locally enhanced bioaccumulation. For example, soil analysis has revealed depositional plumes downwind of historic mercury retorts (Homestake Mining Company, pers. comm. to S. McCord, 2002). The California Air Resources Board estimates mercury emission rates into the atmosphere for all of California of 12,500 kg/yr (27,500 lb/yr), two-thirds of that as windblown dust[19]. It has been shown in other places (e.g., Florida Everglades, Savannah River in Georgia, hundreds of lakes in northern Wisconsin and northeastern Minnesota and Arivaca and Peña Blanca Lakes in Arizona) that the deposition of atmospheric mercury can be solely sufficient to result in fish flesh levels above human consumption guidelines.

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[15] The derivation methodology for all load source estimates is described in the Mercury Conceptual Model Report (Appendix 2).

[16] Known sources contributing to mercury in the atmosphere are listed in Appendix 1.

[17] RELMAP (Regional Lagrangian Model of Air Pollution) is an atmospheric deposition model that accounts for all permitted discharges to air in the US plus a global natural and anthropogenic background level.

[18] Land uses shown in Map 2 are used in the estimate of conveyed mercury, described in Appendix 1.

[19] See www.dtsc.ca.gov/HazardousWaste/HWMP_REP_DraftMercury1.pdf.

The bioavailable fraction of this source may be relatively high due to the rapid oxidation of elemental mercury to divalent mercury in the atmosphere. Therefore, this source appears to contribute disproportionately to fish tissue concentrations.

- ☐ *Discharges of treated municipal and industrial wastewater (3 kg/yr)* – These estimates are based on permitted discharge flow rates and measured (or estimated) mercury concentrations in effluent (Map 6). Typical total mercury concentrations in treated effluent range from 5 to 15 nanograms per liter (ng/L). These controlled sources represent approximately 1% of the total mercury load from the SRW. Nonetheless, some concern exists that because mercury in treated wastewater has a high dissolved fraction (relative to ambient waters) it may be more readily methylated.
- ☐ *Erosion of native soils (47 kg/yr)* – These estimates are based on TSS data in water and assumed background mercury concentrations in native soils Range (Bradford et al., 1996; R. Churchill, pers. comm. to S. McCord, 2001). Based on those values, a large fraction of the total mercury load in the SRW appears to come from these relatively uninvestigated and uncharacterized sources. The majority of the load in this category occurs as cinnabar (HgS), which, although expected to be relatively non-reactive, appears to cause bioaccumulation in Tomales Bay (Whyte, 2000) and in South San Francisco Bay (San Francisco Bay RWQCB, 2000).

Loads computed for key watersheds and extrapolated:

- ☐ *Urban runoff (4 kg/yr)* – These estimates are based on the mass load calculated for Arcade Creek[20] (located in the City of Sacramento), and are extrapolated for other areas based on land use data (Map 2) by assuming that the load per urbanized area is equivalent throughout the SRW. This assumption that Arcade Creek is a representative urban runoff site must be verified by examining other urban runoff sites. Because of the relatively small urban area in the SRW, runoff contributions from urban areas to the total mercury load are minor overall. Methylmercury concentrations in the urban runoff measured in Arcade Creek are elevated in comparison to most other SRWP monitoring sites.
- ☐ *Flows from mineral springs (18 kg/yr)* – These estimates are based on reported flow rates of mineral springs in Mill Creek and the upper Sacramento River (Map 7). Mercury concentrations measured in springs vary by several orders of magnitude[21], so this estimate has significant uncertainty. The available data indicate that the watersheds with the most mineral springs (Mill Creek and Cache Creek) also have some of the highest concentrations of total mercury. Methylmercury concentrations in Mill Creek are also elevated in comparison to other SRWP sites (mean concentration sixth highest among 23 stations).
- ☐ *Runoff and erosion from historic mercury mine sites (3 kg/yr)* – These estimates are based on mass loads calculated for the Cache Creek watershed (where many of the mercury mines are located) and the inventory of historically productive mercury mines in that watershed (Map 7). The database is a combination of the Minerals Resource Data System (MRDS) database developed by the USGS and information from the Division of Mines and Geology. Individual loadings from any of the more than 50 mercury mines are unknown.
- ☐ *Runoff and erosion from historic gold mine sites (61 kg/yr)* – These estimates are based on mass loads calculated for the American River and Feather River watersheds (where the majority of gold mines are located) and the inventory of historically productive gold mines in each watershed (Map 7). The individual loading from any of the more than 3,000 gold mining sites is unknown.

Unknown loads:

- ☐ *Re-suspension of contaminated sediments* – The mass load of mercury currently transported from historic gold mining areas represents only a tiny fraction of the total estimated *3.7 million* kg (8.2 million pounds) of mercury lost to the environment during the operation of these facilities (Churchill,

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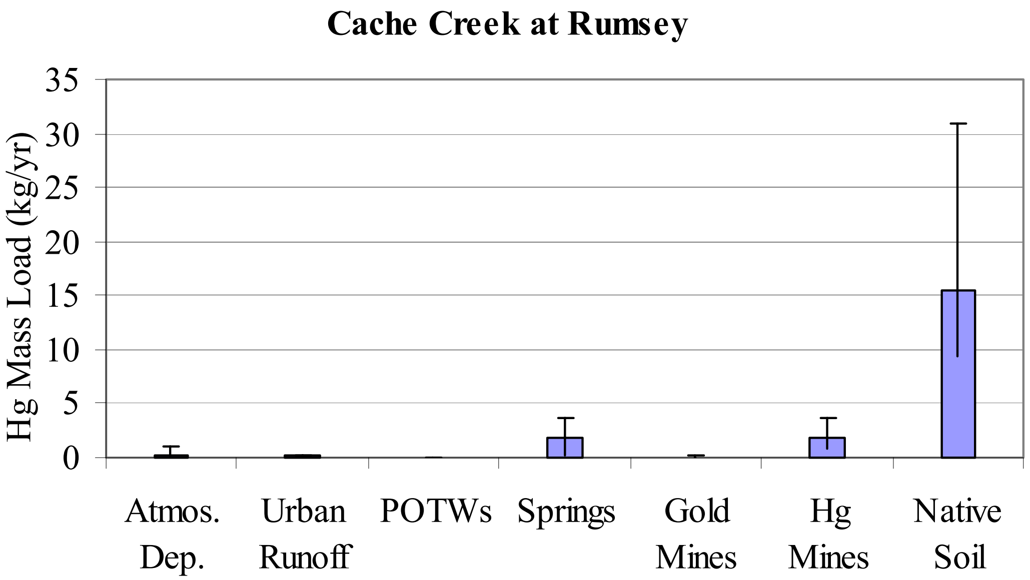
[20] More urban areas in the SRW (see Figure 8) may begin monitoring their streams and urban runoff as part of their stormwater programs.

[21] For example, for two mines less than 1 mile apart in the Cache Creek watershed one showed non-detected total mercury concentrations (<0.5 ng/L) while the other was at 39,000 ng/L.

2000). More than 1.5 billion cubic yards (1.1 billion m^3) of gravels in the Sierras and over 3.6 billion cubic yards (2.8 billion m^3) of dredged flood plain deposits were worked using mercury as the amalgamating agent for gold, spreading even minute particles of quicksilver (more dense and *less* mobile than some contaminated sediment particles) as far as 20 miles (32 km) into downstream waterways (Alpers and Hunerlach, 2000). Additionally, somewhere on the order of *8 million* kg (17.6 million pounds) of mercury was lost in Cache and Putah Creek watersheds[22]. The current disposition of the bulk of the mercury used is not known, though it can be surmised that it has been widely dispersed into the SRW during the century since the use of mercury in gold recovery ceased. Near the end of the hydraulic gold mining era (late 1870s), a total of 51,000 acres (21,000 ha) of farmland in the foothills along the Feather and Yuba Rivers had been buried under debris, and another 22,000 acres (9,000 ha) were partially damaged (Gilbert, 1917). No one has measured mercury concentrations in stream sediments[23] in the SRW. Their load contributions can, like that from gold and mercury mines, periodically become latent sources that are episodically re-introduced and transported farther into the downstream environment.

- *Erosion and leaching of pesticide residue in soils* – Mercury used as a fungicide for wheat and other grains in the state until the 1970s (16 million pounds used on 700,000 acres[24]) is another potential source of mercury in the Sacramento Valley[25]. Although total and methylmercury concentrations in the two main agricultural drains of the Sacramento Valley (Sacramento Slough and Colusa Basin Drain) are high, flow rates are not available for calculating mercury loading rates.
- *Releases from other mineral mines and waste disposal sites* – Mercury loading from other types of mines (e.g., silver, copper, zinc) and land disposal sites have not been quantified due to the complexities and uncertainties involved in such estimates.

Preliminary source loading estimates for two tributary stations (Cache Creek at Rumsey, below several historic mercury mines; and Feather River at Nicholas, below its confluence with the Yuba River) and two mainstem Sacramento River stations are shown in Figure 6. These data suggest that mineral springs and native sediment, both natural features in the watershed, are major sources of total mercury in the SRW.



a)

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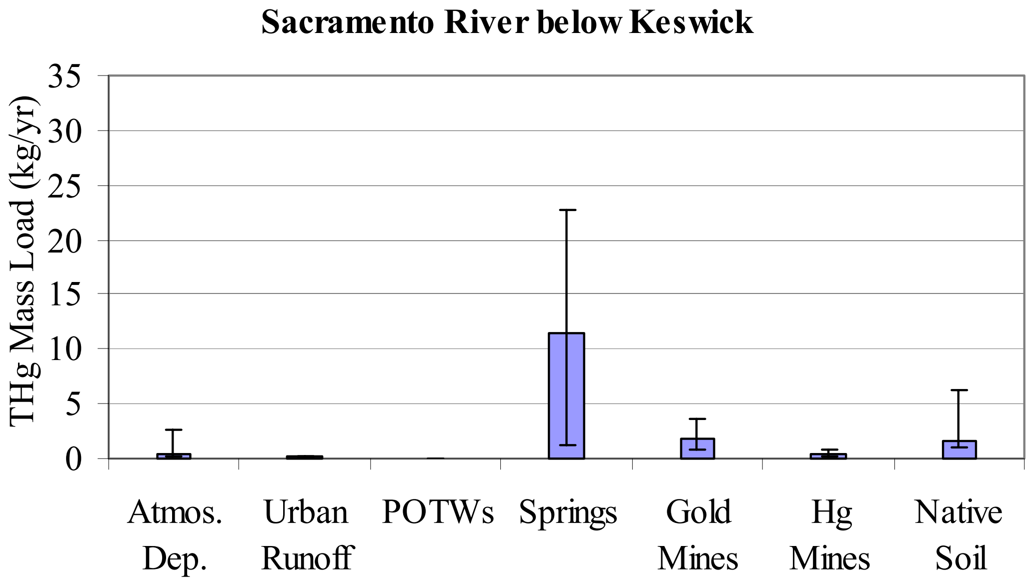
[22] Estimated based on 34.5 million kg lost from mercury mining statewide (Churchill, 2000) with Cache and Putah Creek watersheds producing about 26.3 million of the 103.6 million kg of mercury produced throughout the state.

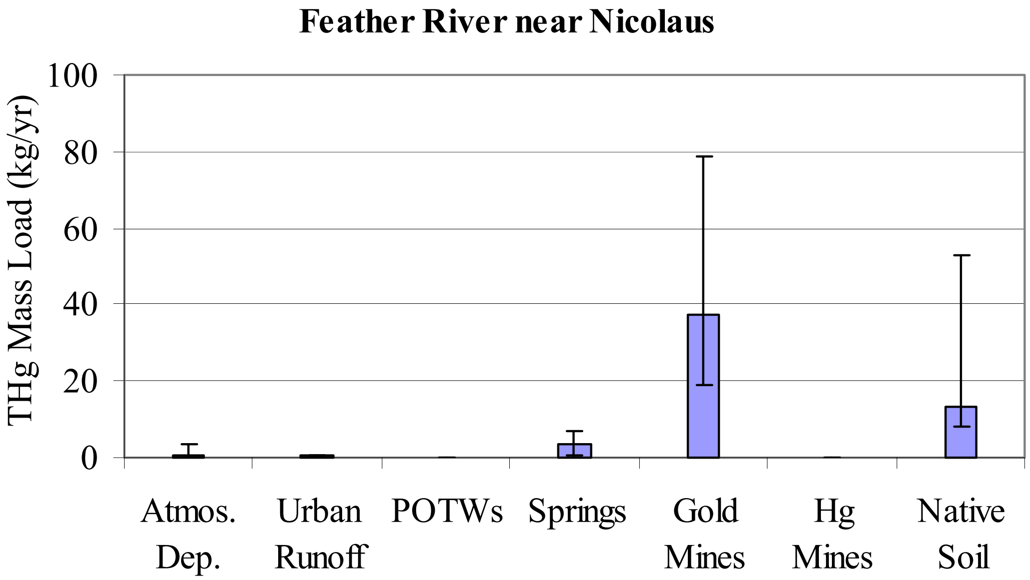
[23] Work by USGS in the Sacramento River focused only on surficial sediments of particle diameter less than 63 μm.

[24] Equivalent to 7.3 million kg on 283,000 ha.

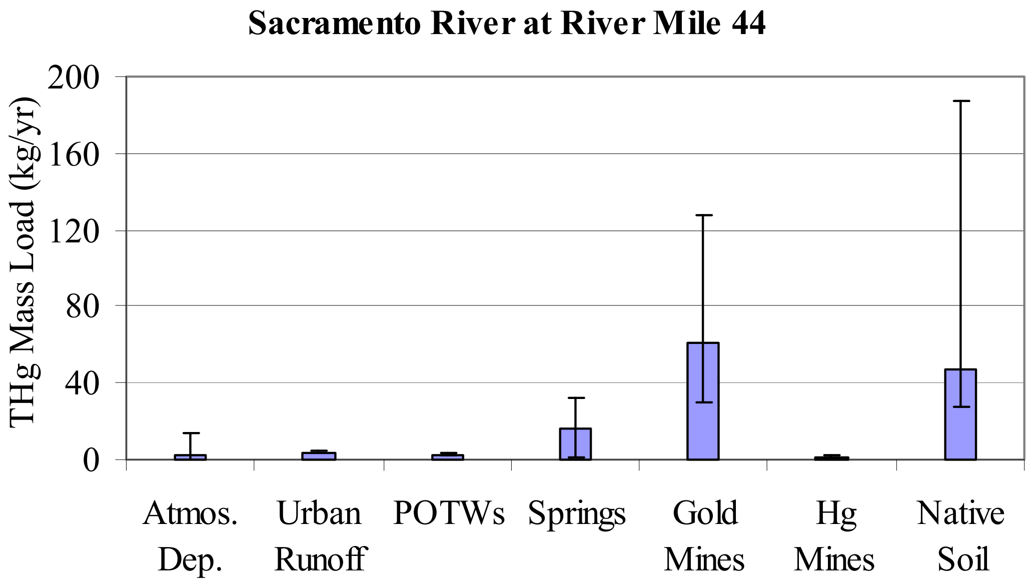
[25] In the 1870s, Colusa County produced a significant portion of the *world's* wheat (McComish and Lambert, 1918).


Sacramento River below Keswick
THg Mass Load (kg/yr)
35
30
25
20
15
10
5
0
Atmos. Dep.
Urban Runoff
POTWs
Springs
Gold Mines
Hg Mines
Native Soil

b)


Feather River near Nicolaus
THg Mass Load (kg/yr)
100
80
60
40
20
0
Atmos. Dep.
Urban Runoff
POTWs
Springs
Gold Mines
Hg Mines
Native Soil

c)



d)

Figure 6. Annual average total mercury (THg) mass loads by source types contributing to a) Cache Creek at Rumsey downstream from several mercury mines, b) the upper mainstem Sacramento River, c) Feather River below its confluence with the Yuba River, and d) in the lower Sacramento River. Note that the vertical scales vary. All load estimates are described in the Mercury Conceptual Model Report (Appendix 1).

Mercury Source Controls

The physical and chemical properties that make mercury useful (e.g., liquid at ambient temperature, highly volatile, and easy to reduce) and its widespread distribution make it very difficult to control. The effectiveness of source control measures depends on both the nature of the source and the characteristics of the control measure. Source controls addressed here include contaminated soil removal or containment, erosion control, treatment of contaminated waters, regional reductions in air inputs, in-stream sediment catchment, revised reservoir operating procedures, consumer product formulations, and consumption advisories.

Removal or Containment of Contaminated Soil and Rock (Linkage 1→2)

Removal and disposal: Highly concentrated mercury-containing wastes (such as those found at some mine sites) are likely candidates for collection and shipment for disposal at approved hazardous waste disposal sites. In relic sluice tunnels from hydraulic gold mining, up to one pound of elemental mercury per linear foot of tunnel can be collected. Collection of mercury collected by individual suction dredgers has been initiated on a pilot basis.

On-site stabilization and containment: Wastes and soils whose mercury concentrations are low but that are high in volume or occupy large areas can often be protected from erosion by the installation of site drainage control facilities, the application of non-contaminated covering soils, planting of vegetation and the implementation of other on-site stabilization and containment measures. Releases to the atmosphere may also be reduced when using this strategy.

On-site encapsulation: Reactive and (or) soluble wastes often require isolation from air and water to prevent their transformation and release. Encapsulation is most suitable for highly sulfidic wastes with a high potential to form acid rock drainage (ARD). ARD can dissolve and mobilize mercury into the downstream environment where it is readily methylated. This technique has been employed effectively at gold mines in the Sierras.

Erosion control: Erosion of mercury-laden soils from contaminated sites can be reduced by common practices such as drainage modifications, re-grading, re-vegetation and slope stabilization. If implemented on a grand scale, resulting decreases in water turbidity may have the additional benefit of increased photo-degradation (breakdown) of methylmercury.

Effectiveness of Contaminated Site Controls: Measures used to control mercury loadings from acutely contaminated sites (removal, stabilization, encapsulation) can be highly effective locally. Some portion of the mercury from the larger contaminated landscape will be transported from the site over time by the natural processes of erosion, evasion, and burial. Capped mine waste (soil material) has been measured to have flux rates equivalent to the same uncapped waste (Gustin, 2000).

Mercury Sources Controls (Linkage 1→2)

- *Removal or Containment of Contaminated Soil and Rock*
- *Treatment of Contaminated Discharge Waters*
- *Reduction of Regional Emissions to the Atmosphere*
- *Reduction of Mercury Use*

Treatment of Contaminated Discharge Waters (Linkage 1→2)

Passive treatment of discharge waters: Chemical and/or biological reduction of dissolved mercury in mineral spring discharges and some mine runoff may prove to be an effective control measure. *In situ* treatment technologies for electro-active metals, such as chromium, arsenic, selenium, uranium and mercury, using a zero-valent iron, porous barrier wall have proven effective elsewhere (Blowes et al., 1999). Preliminary laboratory batch testing of Coast Range mineral spring waters conducted at the University of Waterloo, Canada, has indicated that the removal of mercury from solution to very low levels is sufficiently rapid using readily available reactive media to warrant further investigation. Geochemical modeling suggested that mercury was removed from solution in conjunction with the precipitation of other mineral phases, most likely ferrihydrite or related iron oxyhydroxides. Further laboratory testing has confirmed that removal of mercury to concentrations of less than 0.0005 mg/L can be achieved in batch reaction vessels. This concentration is still 50 times higher than concentrations measured at many sites with no identified contamination sources where fish mercury concentrations exceed target levels.

Active treatment of discharge waters: Active treatment for the removal of copper and other metals (including mercury) using lime precipitation has been widely applied to the acidic leachate from historic base metal mines. Remediation at base metal mines Penn Mine and Iron Mountain Mine employed this treatment technology; however, no data evaluating the effectiveness of this technology at removing mercury have been located. Active pretreatment of industrial wastewater containing mercury is generally required prior to its release to public sewers. Additional treatment for removal of mercury from municipal wastewaters would require use of membrane technologies (microfiltration or reverse osmosis), which involve high energy and very high unit costs (dollars per pound removed) in comparison to other controls.

Effectiveness of Discharge Controls: Secondary treatment (sedimentation and biological reactors) of industrial and municipal wastewater can be effective at removing mercury (~95%). Additional treatment is possible, but generally at a very high cost relative to the incremental load reduction achieved. For the case of a highly concentrated acid mine drainage, the on-site lime-neutralization, high-density-sludge (HDS) treatment plant at Iron Mountain Mine removes approximately 99% of the copper and zinc (CH2M-Hill, 1998). Extremely high mercury concentrations also may be effectively removed by treatment. However, where mercury source concentrations are not significantly elevated, treatment would become more costly per unit reductions and potentially ineffective at producing acceptably low mercury concentrations in effluent.

Reduction of Regional Emissions to the Atmosphere (Linkage 1→2)

Use of alternative non-mercury containing fuels: Mercury emissions from coal-fired power plants are higher than mercury emissions from power plants that rely on natural gas, fuel oil, or wood. Converting to alternative energy sources is possible, but certainly a long-term proposition.

Emission control devices: Federal and state rules are in effect or soon forthcoming for controlling mercury emissions from municipal waste combustors by up to 90 percent.

Effectiveness of Atmospheric Emissions Controls: The control of some individual sources of mercury release to the atmosphere can be highly effective. Fuel substitutions and emission controls have the potential to effectively eliminate some sources of release. The Minnesota Pollution Control Authority has initiated investigations of various energy alternatives[26]. Some lake core samples show evidence of recent declines in atmospheric deposition, coincident with decreased usage regionally (Wiener et al., 2002). However, the relative effectiveness of implementing such measures needs to be considered in light of the substantial amounts of mercury released to the atmosphere by evasion from natural soils and the combustion of natural vegetation during wildfire events and the current global atmospheric mercury burden.

Reduction of Mercury Use (Linkage 1→2)

Elimination of the mercury used in consumer products: The elimination of the mercury used in consumer products is an obvious and reasonably easily implemented step. It has the added advantage of avoiding accidental release and exposure of the users of the products.

Effectiveness of Use Controls: Given the mobility of mercury in the environment, the elimination of mercury used in consumer products could eventually reduce mercury concentration in target species. The California State legislature passed a bill in 2001 (S.B. 633) that prohibits the sale of mercury fever thermometers and novelty items, restricts school purchases of mercury items, and requires special handling of mercury switches from discarded vehicles. Additional reductions in the SRW beyond this measure are unlikely.

Question 2b – How do fate and transport processes impact mercury concentrations in downstream locations (Linkage 2→3)?

Answer – Mercury may be physically, chemically and biologically transported, transformed and entrapped, or otherwise modified in quantity or character as it moves through the environment. Reservoirs reduce the mass load of total mercury that would otherwise be available to move downstream by allowing mercury adsorbed to suspended sediment to settle. However, conditions of low dissolved oxygen promote the methylation of some portion of the trapped total mercury, which can result in locally elevated fish tissue levels.

Mercury deposited from the atmosphere may be subject to repeated episodes of volatilization and re-deposition, resulting in gradual dispersion in a process know as “grasshoppering.” Monitoring of total mercury in the SRW indicates that its major movement in water occurs during peak river flow events, which carry mercury adsorbed onto particulate material (Domagalski, 2001). Under normal or low-flow conditions, a significant lag (or loss) appears when source load data are compared to downstream total mercury loads. This finding suggests that adsorbed mercury settles with the particulate load in reservoirs, wetlands, quiescent river reaches, and shifting riverbeds. For this reason, the evaluation of mercury movement in the SRW is often segmented between locations upstream and downstream of reservoirs. As noted in the introduction, large dams, along with over one thousand minor dams on smaller tributaries, control almost every major tributary in the SRW.

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[26] See www.pca.state.mn.us/air/pubs/merc-sec8.pdf.

Production of methylmercury has been found to occur particularly where deeper waters are seasonally anaerobic (e.g., Driscoll et al., 1994). Thus, although total mercury concentration could decrease as water passes through a reservoir, methylmercury concentration could increase locally. None of the long-term monitoring stations operated by SRWP, USGS or DWR are located above major dams. Therefore, the extent to which lakes and reservoirs may reduce or increase the concentration of mercury in target species is not sufficiently characterized. A one-year monitoring study performed at Englebright Reservoir (LWA, 1997) indicated that methylmercury concentrations and bioaccumulation was lower below the reservoir, but additional monitoring is required to confirm this result.

Monitoring at Davis Creek Reservoir (Coast Range) indicates deposition rates of 3 to 300 kg per year (6.6 to 660 lb/yr) in the reservoir[27]. Methylmercury concentrations increase in the reservoir and in a wetland zone immediately downstream and bioaccumulate in aquatic macroinvertebrates in the immediate area. Yet farther downstream, methylmercury concentrations in water and in fish are not elevated (Homestake Mining Company, 2002).

Removal or Containment of Contaminated Aquatic Sediments (Linkage 2→3)

Dredging: Highly concentrated mercury-containing sediments in waterways and reservoirs of the SRW may be removed by dredging.

Adding clean sediment: Parks and Hamilton (1987) suggested using clean clay sediments to mitigate local sources (bottom sediments). *In situ* sediments could be stirred up upstream of the hot spot or “new” sediment imported and added directly into the stream.

Effectiveness of Aquatic Sediment Controls: The major problem with dredging is the vast extent of mercury contamination (several million cubic yards in volume) coupled with the subsequent need for disposal. Parks and Hamilton (1987) estimated that the burial approach might be more effective and less costly than dredging or land disposal of contaminated sediment. In an early evaluation of the Mercury Cycling Model (MCM), addition of sediment profoundly reduced mercury concentrations in the water and in biota. The problem with this method is the presence of other sources (either upstream or downstream of the river reach being treated) continuing to leach mercury into the waterway, reducing the effectiveness of the added sediment over time. Also, in the Carson system, scientists have observed that, for several years, sediment mercury levels in the Basin were declining due to deposition of recent sediments that are lower in mercury concentration. However, a heavy snow accumulation year in the mountains and corresponding large spring runoff scoured the more recent, lower mercury-laden sediments and re-exposed the higher mercury-laden sediments below.

Controls Used in Water to Reduce Transport (Linkage 2→3)

Construction and/or maintenance of in-stream sediments traps (physical sinks): Sediment traps, both natural and constructed, provide locations where accumulated mercury can be collected and removed for off-site disposal. Cache Creek Settling Basin and Yuba River’s Daguerre Point Dam are sediment traps already constructed for the two tributaries with the largest total mercury loads per area (and draining large areas). The opportunity may exist to remove sediments deposited behind existing sediment traps in the SRW as a mercury removal measure.

Infiltration: Mercury-laden waters can be treated by infiltration in basins or spreading grounds. Because mercury partitions onto solids, infiltration may sequester a significant portion of the mercury load.

Effectiveness of Fate and Transport Controls: Sediment traps are generally effective at removing 40%-80% of the sediment load (Brune, 1953); although removal is lower for the smaller, lighter particulates that tend to adsorb mercury. Nonetheless, monitoring of aquatic biota above and below reservoirs in the motherload has demonstrated modest reductions in mercury concentrations in downstream biota (Slotton et al., 1997a). However, in reservoirs that are sufficiently deep to seasonally stratify, mercury on sediment trapped behind dams accumulates at the water-sediment interface where it can be methylated and enter into the food chain. Some of the highest fish flesh concentrations in the SRW have been found in fish

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[27] The high variability is related to extreme inter-annual variability in hydrologic conditions in that watershed.

from such reservoirs, which have been listed as impaired by the RWQCB (see response to Question 1a). Infiltration effectiveness is highly site-specific, depending on the soil conditions (e.g., permeability, adsorptive capacity) and design (e.g., loading rate, distance to groundwater).

Question 2c – What factors affect ambient concentrations of methylmercury (Element 3) and rates of bioaccumulation and biomagnification (Linkage 3→4)?

Answer – Research in the SRW, Delta and elsewhere indicates that mercury methylation rates vary depending on several environmental factors, but are typically enhanced in wetland environments. Bioaccumulation processes depend on the amount of mercury in surficial sediments, the water quality at the sediment/water interface, and local food web dynamics. The functional relationships among these factors in the SRW are a topic of ongoing research.

Mercury Methylation (Linkage 2→3)

Rates of methylation in water, sediments, and aquatic organisms depend upon numerous environmental factors, including type and abundance of microorganisms and organic matter, pH, temperature, redox potential, sulfate concentration, and mercury concentration (D'Itri, 1990). Demethylation is known to simultaneously occur with methylation in both reservoirs and wetlands. Net availability of methylmercury for bioaccumulation varies depending upon the relative rates of methylation and demethylation reactions (Korthals and Winfrey, 1987).

Sulfides have been thought to inhibit mercury methylation by binding with available mercury (Marvin-DiPasquale, pers. comm. to DTMC), but this effect was not seen in the SRW's Central Valley rice wetlands (Domagalski, 2001). Furutani and Rudd (1980) also observed no relationship between methylmercury sulfide concentrations (possibly due to excess of ferrous iron in surface sediments in that study). Benoit et al. (1999) found that there is an optimal ionic strength of the water at which neutrally charged divalent mercury can be methylated. Higher sulfide (or other anions such as chloride) concentrations form poly-anionic complexes that inhibit methylation. This complicating factor should be considered when considering wetland management and identifying high-risk areas.

A recent study by USGS in three areas in the Delta (Marvin-DiPasquale and Agee, 2002) showed that net methylation rates in Delta sediments (spiked with labile mercury under laboratory conditions) may be greatest in late winter (February and March) when sulfide reduction is low and demethylation rates are low due to low temperatures and reduced bacterial activity. The authors found that net methylation rates were not functionally related to concentrations of mercury, organic carbon, or pH in sediment.

Net methylation rates accelerated by three orders of magnitude in the Wabigoon River system (Canada) through increased bacterial activity (Rudd et al., 1983). These researchers found that methylation rates are related to the availability of food (e.g., organic material) and are inversely related to amount of mercury-binding particulates.

Kelly et al. (1995) found no general predictive relationship between concentrations of total mercury and methylmercury in water, based on work in the Experimental Lakes area of northwestern Ontario, Canada. The authors note that individual characteristics of an ecosystem are more important in determining methylmercury production than the total mercury concentrations.

In a national pilot study of mercury contamination in aquatic ecosystems, USGS found that wetland density (area of wetlands per area of watershed) was the single most important basin-scale factor controlling methylmercury production. That study also found that methylmercury production in sediments was proportional to total mercury levels at low concentrations, but that methylation leveled off at higher total mercury levels (Krabbenhoft et al., 2001).

USGS' research in the SRW found that both total and methylmercury concentrations in water were highest during the wet season, but *inversely* related in surficial sediment (that is, total mercury concentrations tended to be higher where methylmercury concentrations were lower, and vice-versa)

(Domagalski, 2001). SRWP data for methylmercury in water show no statistical correlation with flow rate or with total mercury in water (average $r^2<0.1$; $p>0.05$ for all sites).

Freshwater wetlands also have been found to increase methylation rates in the Central Valley (Domagalski, 2001). Sediment methylmercury concentrations and methyl:total mercury ratios were significantly greater in highly vegetated marsh habitats as compared to adjacent Delta channel and mudflat environments. Methylation potential experiments showed that flooded wetland sediments exhibited 2-30 times greater potential to produce methylmercury than aquatic sediments of adjacent channels and flats. But methylmercury levels (in water, sediment, and biota) are lower in the central Delta, in an area surrounded by wetlands, leading to supposition that this portion of the Delta may act as a sink for methylmercury (Slotton et al., 2001). Enhanced demethylation or food chain effects could potentially explain this “sink”.

The uncertainty in quantifying methylation rates in a predictive way is a key knowledge gap inhibiting decisions on where to initiate remediation activities. The factors that drive methylation rates in the SRW are undetermined. Locations where those factors occur (e.g., water chemistry conditions, sediment conditions, food web characteristics) are also largely unknown.

Mercury Bioaccumulation (Linkage 3→4)

A popular hypothesis to describe mercury bioaccumulation, as stated by Edwards et al. (1999) and building off earlier work by Mason et al. (1995), is that phytoplankton initiate the enrichment of methylmercury from the water column by accumulating methylmercury in their cytoplasm. Zooplankton graze on the phytoplankton, as do invertebrates and lower trophic level fish, eventually leading to bioaccumulation in the food chain. Dietary uptake probably accounts for more than 90 percent of the total uptake of methylmercury in wild fishes, and fish probably assimilate from 65 to 80 percent or more of the methylmercury present in the food they eat. Concentrations in fish are influenced by their size, diet, sex, and trophic position as well as water chemistry, mercury methylation rates (Wiener et al., 2002). Food web structure appears to play a major role in bioaccumulation exposure, and it may vary considerably from site to site within the watershed, and from season to season.

Pickhardt et al. (2001) found that increased algae concentrations decreased mercury concentrations in zooplankton. Stemberger and Chen (1997) found that mercury in fish sampled in 96 northeastern US lakes increased in association with chain length[28]. Chen et al. (2000) found that concentrations in fish were *inversely* related to concentrations in small plankton, in what is being referred to as “biodilution”. As a local example, monitoring at Davis Creek Reservoir indicates that mercury levels in fish have steadily increased while sediment inorganic mercury loading decreased over the past six years. The cause may be linked to a shift in trophic status that has reduced planktonic algae or to changes in other variables (Homestake Mining Company, 2002).

Concentrations of total mercury and of other factors affecting methylation and bioaccumulation may change rapidly, such that a measured concentration in water is only a “snapshot” of exposure at one time. In cases where water quality monitoring is carried out with low frequency (monthly or quarterly), rapid changes in environmental conditions pose problems for developing an understanding of the factors driving bioaccumulation.

The SRWP has measured methylmercury both in water and in fish tissue at (or in proximity to) ten stations throughout the SRW[29]. Length-normalized fish tissue concentrations are less correlated to station-averaged methylmercury concentrations ($r^2=0.25$) than found elsewhere, indicating that other factors also may strongly influence bioaccumulation rates. The data cannot be adequately segregated by physiographic zone[30] or fish species because of the limited dataset (i.e., each zone has fewer than five stations with data, and the same species are found in fewer than five locations).

Recent CALFED-funded research throughout the Cache Creek watershed, studied these relationships intensively (Domagalski et al., 2002). Preliminary results indicate that invertebrate bio-indicators provide

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[28] “Chain length” refers to the number of predator-prey levels in the food chain.

[29] See Table 2.

[30] Sierras, Upper Sacramento River, Lower Sacramento River, and Sacramento Valley agricultural drains.

excellent measures of relative biotic mercury exposure in relation to fish methylmercury bioaccumulation. They also indicate that, while aqueous total mercury is generally co-correlated with other aqueous mercury parameters on a watershed-wide basis, aqueous total mercury is not predictive of biotic methylmercury accumulation at individual sites. Aqueous raw methylmercury was found to be by far the best predictor of corresponding methylmercury bioaccumulation in the lower trophic levels, which in turn were highly predictive of corresponding methylmercury bioaccumulation in large fish.

Watras and Bloom (1992) found that inorganic mercury accumulated substantially through the food chain, surpassed by MeHg only in higher predators (mainly fish). But invertebrates in Sierra streams had 69%-92% of their total mercury load in the form MeHg. Even biota collected *at* gold mines (contaminated with elemental mercury) appear to have elevated mercury concentrations in their tissue[31]. In the Cache Creek watershed, contamination from inorganic mercury sources (mineral springs) was only found in the reaches near to the sources. Farther downstream, mercury concentrations in biota returned to background levels, suggesting that the additional HgII quickly becomes biochemically unavailable without intervention in the Cache Creek watershed.

Biological findings to date indicate no discernible localized increase in net methylmercury bioaccumulation in flooded wetland tracts versus adjacent aquatic habitats within Delta sub-regions. Some of the most well developed, highly vegetated wetland tracts exhibited reduced levels of localized net mercury bioaccumulation (Slotton et al., 2001).

In summary, different relationships between methylmercury in water and sediments, and mercury in fish tissue have been demonstrated in specific environments. The referenced studies concur with local data that we cannot generalize across different kinds of waterbodies or conditions due to the influence of multiple site-specific factors. Regarding total mercury levels in water, no evidence exists to support a relationship with mercury levels in fish tissue.

Mercury Controls for Linkage 2→3

Methylation Controls

- *Sulfate/sulfide stimulation and inhibition*
- *Construction or restoration of net demethylating wetlands (biological sinks)*
- *Wetland management*

Bioaccumulation and Biomagnification Controls

- *Selenium dosing*

Controls Used in Water to Reduce Methylation (Linkage 2→3)

Sulfate/sulfide stimulation and inhibition: Sulfides are thought to inhibit mercury methylation by binding with available mercury. In the Florida Everglades, managing the sulfate load from agricultural activates upstream of the Everglades appears to be as important, or possible more important, than mercury source management.

Construction or restoration of net demethylating wetlands (biological sinks): Wetland habitats host both methylating and demethylating bacteria. In addition, some wetland species have the capacity to uptake or otherwise sequester mercury (deLacerda and Salomons, 1998). Decay of vegetation can in turn release mercury for renewed uptake or transport elsewhere. The balance among the various processes determines whether any particular wetland has the potential to function as a control measure by ultimately contributing to the reduction of mercury in target species. The current state of knowledge is insufficient to describe with certainty the wetland conditions that could function to reduce mercury.

Wetland management: Better understanding of the function of wetland habitats could provide insight into methods of physical, chemical, and (or) biological alteration that could enhance their potential to function as mercury control measures. For example, aeration and destratification of seasonally stratified reservoirs

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[31] Based on recent studies by USGS at Boston Pit Mine and other gold mining sites in the Sierras.

are means of minimizing the anaerobic conditions known to promote methylation (McCord, 1999). Manipulation of factors such as nutrient availability, water depth, and ecological structure may also be found to alter the fate of mercury within particular wetland types[32].

Controls Used in Water to Reduce Bioaccumulation and Biomagnification (Linkage 3→4)

Selenium dosing: Selenium (measured as total selenium) is known to reduce toxicity of mercury in biological systems (Cuvin-Aralar and Furness, 1991), but selenium also has been found to cause adverse reproductive effects of methylmercury toxicity in avian species (Wiener et al., 2002). Because the mechanisms underlying the inhibition are not well understood, more research is required before implementing a selenium-dosing project[33].

Effectiveness of Methylation and Bioaccumulation Controls: Because the process of methylation cannot be functionally related to a manageable set of real-world environmental conditions, the effectiveness of these control measures is uncertain. A better understanding of wetland function as it relates to mercury methylation is a high priority for future research, particularly in light of the numerous proposals for wetland restoration within the SRW and the Delta.

Question 2d – What reduction in risk to humans and wildlife is produced by decreases in fish tissue levels for a given fish species (Linkage 4→5)?

Answer – Reducing risk of mercury requires knowledge of the relationship between risk and fish tissue concentration, which in turn requires knowledge of the amounts of certain fish species consumed by sensitive humans and wildlife. This question highlights an existing knowledge gap.

Mercury is categorized by USEPA as a systemic toxicant (CTR, May 2000), with a threshold dose below which no adverse effect in humans is predicted. The reference dose (RfD) for mercury is defined as a level at (and below) which no likely risk of adverse effect in humans is anticipated. Doses that are less than the RfD are not likely to be associated with any health risks. As the frequency of exposures exceeding the RfD increases and as the size of the excess increases, the probability increases that adverse effect may be observed in the human population (USEPA, 2000)[34]. This indicates that the RfD is not a clear delineator (threshold) of adverse effects.

Methylmercury lends itself to an assessment of exposure through direct measurement in blood and hair. These measurements have been used as biomarkers of exposure in key studies, which have led to development of the USEPA reference dose for methylmercury and ultimately the fish tissue mercury target value selected for use in this plan. The National Research Council performed a “margin of exposure” (MOE) analysis for the US population to assess the risk of adverse effects of methylmercury in this country (NRC, 2000). An MOE analysis is a *method of characterizing risks*, which compares the levels of methylmercury exposure of a given population to the observed (or estimated) critical level of exposure associated with an increase in adverse effects (e.g., No Observed Adverse Effect Level, Benchmark Dose Levels). Measurement of methylmercury in blood and hair, coupled with knowledge of fish consumption history exists as a possible tool in future risk assessments in the SRW.

An initial assessment of creel survey data collected by the California Department of Fish and Game in the SRW over a recent two-year period indicates high fishing intensity at selected locations (Figure 7). Comparing this information with Figure 4 and Table 1 shows that high fishing intensity overlaps with high concentrations of mercury in specific fish species in the lower Sacramento, Feather, and American Rivers and in the Delta. Additional study is needed to determine fish consumption rates for species of concern in these areas of highest fishing intensity.

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[32] Such factors are discussed in more detail in Appendix 2.

[33] John Gunn (Coop. Freshwater Ecology Unit, Laurentian University, Sudbury, Ontario, Canada) has some recent data on field measurements of Hg and Se in fish showing positive effects of Se. Hans Hultberg in Sweden is actively researching this question.

[34] Also stated in the California Toxics Rule (May, 2000) preamble, page 31,693.

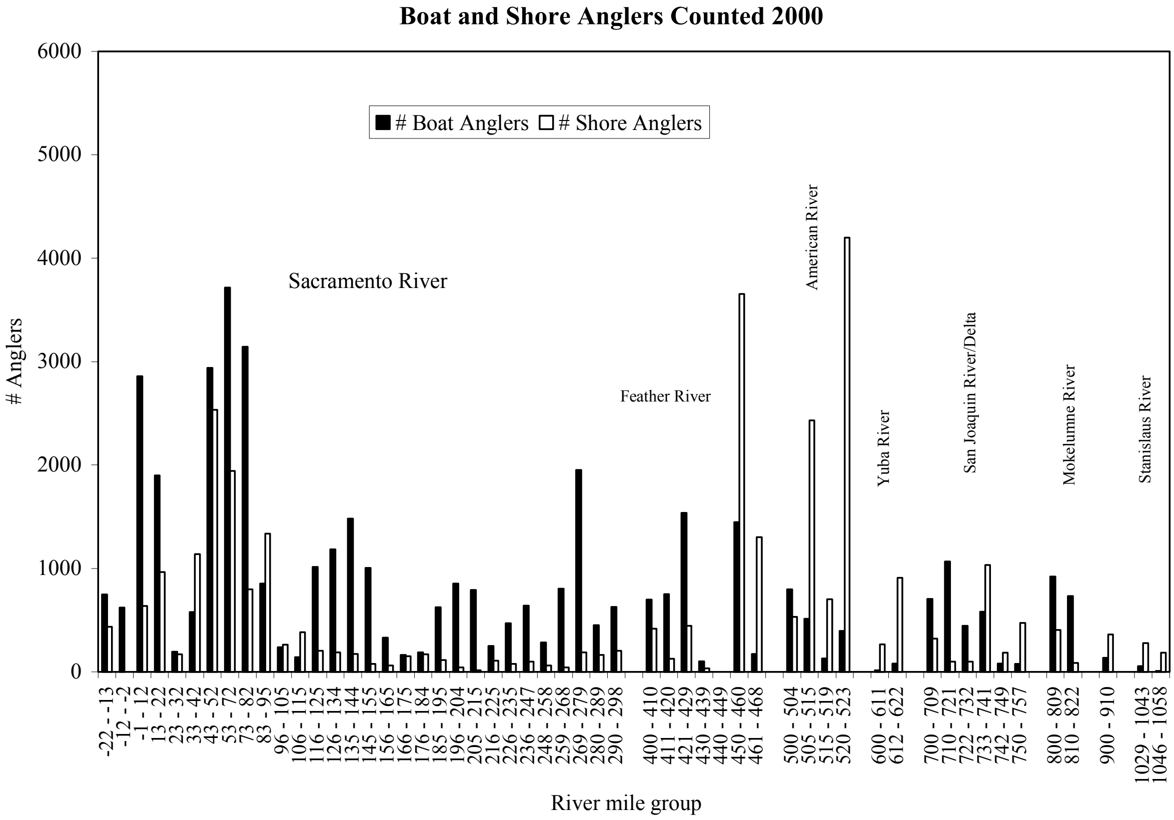


Figure 7. US Department of Fish and Game's Central Valley Angler Survey results for the Sacramento River, 2000. Anglers are concentrated in the areas where fish tissue mercury is highest (lower Sacramento, Feather and American Rivers).

Controls Used on Consumers (Linkage 4→5)

Consumption advisories: Fish consumption warnings and the education of the public about the risks of consuming mercury-containing fish are the only immediate measures that can reasonably be expected to reduce the risks of human exposure. They would have no impact on ecological risk.

Effectiveness of Fish Consumption Controls: Modification of human fish consumption patterns is the only control measure that can, at this time, be predicted with certainty to protect human health from excess mercury uptake. However, because risk education and warnings cannot reach all subjects and because some number of people will ignore such warnings, education and warnings alone cannot be expected to protect 100% of the at-risk population. It should also be noted that a reduction in risk may not necessarily follow decreases in methylmercury concentrations in edible fish if individuals respond to such reductions with increased fish-consumption rates. This control strategy would not affect risks of exposure to wildlife.

Question 2e – What level of certainty is there in quantifying the linkages between a remediation project (source reduction or bioaccumulation reduction) and fish tissue decreases?

Answer – Uncertainties in expected effects increase the farther the point of analysis is from the sources, with significant unknowns regarding aggregate effects of multiple source reductions, mercury transport and transformation, bioaccumulation and

biomagnification. Uncertainties regarding risk result from the lack of knowledge regarding fish consumption patterns and inherent uncertainties in the evaluation of effect thresholds. Because of the uncertainties in these important contributing factors, certainty in the overall linkage analysis is currently low. A survey of mercury remediation projects elsewhere indicates only moderate potential for success. Mercury source control efforts documented elsewhere have proven effective at reducing loads and fish tissue concentrations in severe loading situations. However, these efforts have not reduced fish tissue concentrations below the 0.3-mg/kg target level. Models for representing quantifiable elements and linkages are available but have not been employed to date in the SRW due to various limitations.

A key consideration is the functional relationships that exist in the SRW for each of the above "linkage elements". The range of possible relationships (such as between total mercury in water and percent change of methylmercury in fish tissue) has a simple linear 1:1 relationship at one end of the spectrum, through a continuum that includes other linear (e.g., 2:1, 1:2, 1:5) and nonlinear relationships, and concludes with a finding of no relationship at the other end of the spectrum. This range is shown graphically in Figure 8. One goal of this Plan is to know which type of relationship fits each of the four linkages, and thereby being able to predict changes in mercury concentrations in fish as other linkage elements are changed.

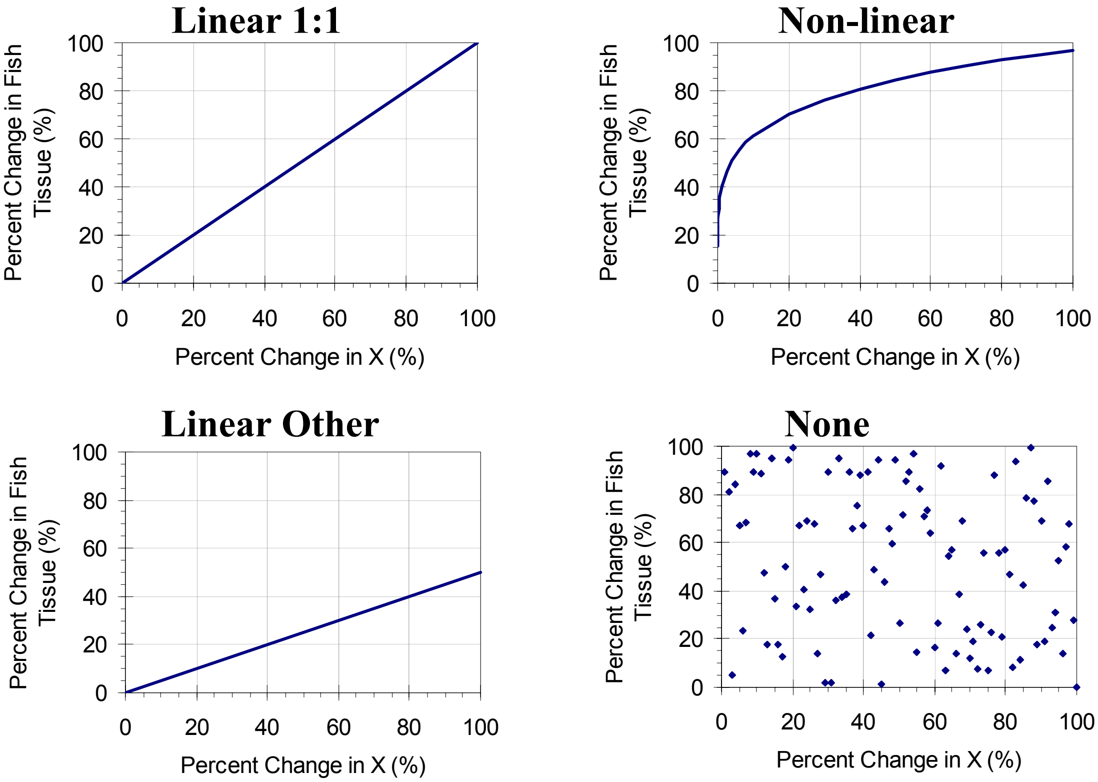


Figure 8. Possible linkage relationships. Although most mercury studies assume a 1:1 relationship between source and fish tissue, our goal is to know which type of relationship fits each of the five linkages.

Most linkage analysis work completed to date in support of mercury studies (particularly TMDLs) has been based on assumptions that reducing loads of mercury to the environment will have a 1:1 effect of reducing fish tissue concentrations within a planning horizon (typically about 10 years). Table 3 indicates the affects of different transfer efficiencies between linkages on relating source reductions to fish tissues within a specified time (say, 10 years). In the first row of numbers all the links are assumed to have a 1:1 transfer (100% efficiency), and so a 50% reduction in the only source (or all sources) corresponds to a 100% reduction in fish tissue. The affects of less efficient transfers are explored in the remainder of Table 3. For instance, if each of the other links were 50% efficient at transferring mercury, a 50% reduction in sources would result in only a 13% reduction in fish tissue concentrations. The lower rows are more applicable for the SRW where multiple source types and areas contribute to mercury in fish. If only 10% of the load is addressed (column 1) and transfer efficiencies are only 50% effective, fish tissue concentrations would only drop by 1.3% in this example.

Table 3. Effects of transfer efficiencies between linkages.

Relative Load to Fish* (Element 1)	Source Reduction (Link 1→2)	Pathway Interruption (Link 2→3)	Bioaccumulation Reduction (Link 3→4)	Fish Tissue Reduction (Element 4)
100%	100%	100%	100%	100%
100%	50%	50%	50%	13%
100%	25%	25%	25%	1.6%
100%	10%	10%	10%	0.1%
10%	100%	100%	100%	10%
10%	50%	50%	50%	1.3%

* The percentage of the mercury in fish tissue that comes from the remediated source.

These results demonstrate the importance of understanding and reducing uncertainties in this linkage analysis. The results could be skewed by the food webs or other water quality conditions that impact these linkages.

A "power analysis" can be used to predict the probability that a statistical trends analysis of monitoring data will reveal a significant trend over time due to remediation activities in the watershed. Results (see Appendix 1) indicate that if total mercury concentrations were reduced by 10% and then monitored for 10 years, there would be only a 40% chance of detecting the effects of that reduction. Detecting changes in fish tissue concentrations, the ultimate target for this plan, would require greater reductions and a longer monitoring period because of the smaller dataset and greater variability in the existing data.

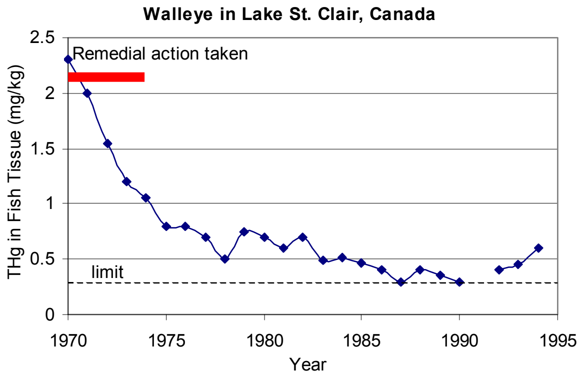
Survey of Remediation Effectiveness

A literature review of mercury contamination and remediation case studies has been undertaken. Figure 9 illustrates monitoring results for mercury in fish tissue at various locations downstream of remediated sites. A listing of the case study locations, sources controlled, and control measures employed is provided in Table 4. Mercury concentrations in edible fish tissue generally have declined subsequent to reductions in major mercury loads (Becker and Bigham, 1995). No cases have been reported, however, to demonstrate that levels below current consumption advisory concentrations or USEPA criterion levels (e.g., 0.3 mg/kg) can be achieved even decades after elimination of dominant sources (Turner and Southworth, 1999). Although similar patterns of mercury contamination from gold mining elsewhere have been published (Ebinghaus et al., 1999), no reports have been found documenting the effects of remediation.

The only detailed investigation found of potential *in-stream* remediation to reduce mercury contamination (methylation and bioaccumulation) has been for the Wabigoon River in Ontario, Canada (Rudd et al., 1983). Options seriously considered included sediment addition and resuspension (to bury or remove contaminated clays) and selenium addition (to inhibit bioaccumulation). Due to various considerations, none of the proposed work was ever carried out (J. Rudd, pers. comm. to S. McCord, 2002). The

METAALICUS project is attempting to determine the relationship between atmospheric deposition of mercury and mercury in fish[35]. Results of this effort will not be available before 2004.

Because of the widespread dispersal of the mercury released from mining operations, it is difficult to postulate that a traditional control approach of locating and removing or stabilizing the contaminant at its source could be employed to consequentially reduce the concentration of mercury in the flesh of target fish species. Public policy decisions to implement mercury source controls will be difficult in light of the current inability to predict the likely benefits of such controls.



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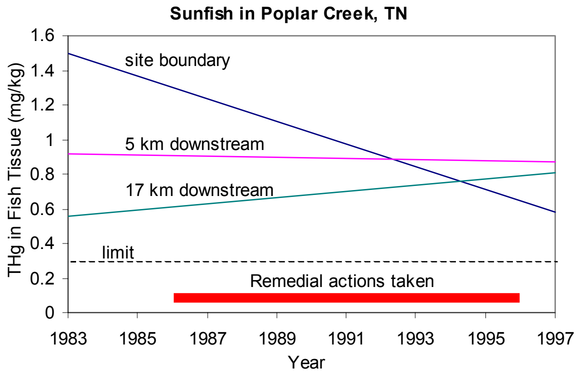

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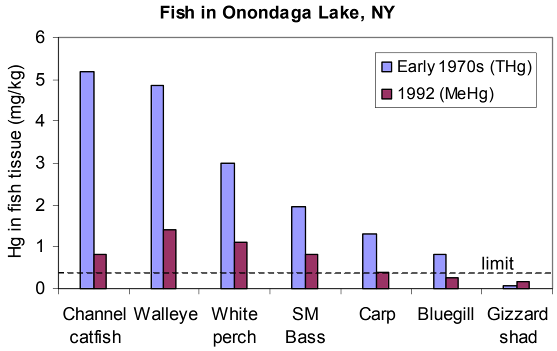

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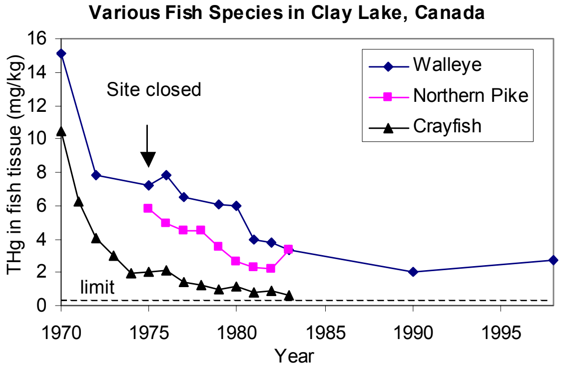

d)

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[35] METAALICUS stands for Mercury Experiment To Assess Atmospheric Loading In Canada and the United States. See project summary at http://www.biology.ualberta.ca/old_site/stlouis.hp/announcement.htm.

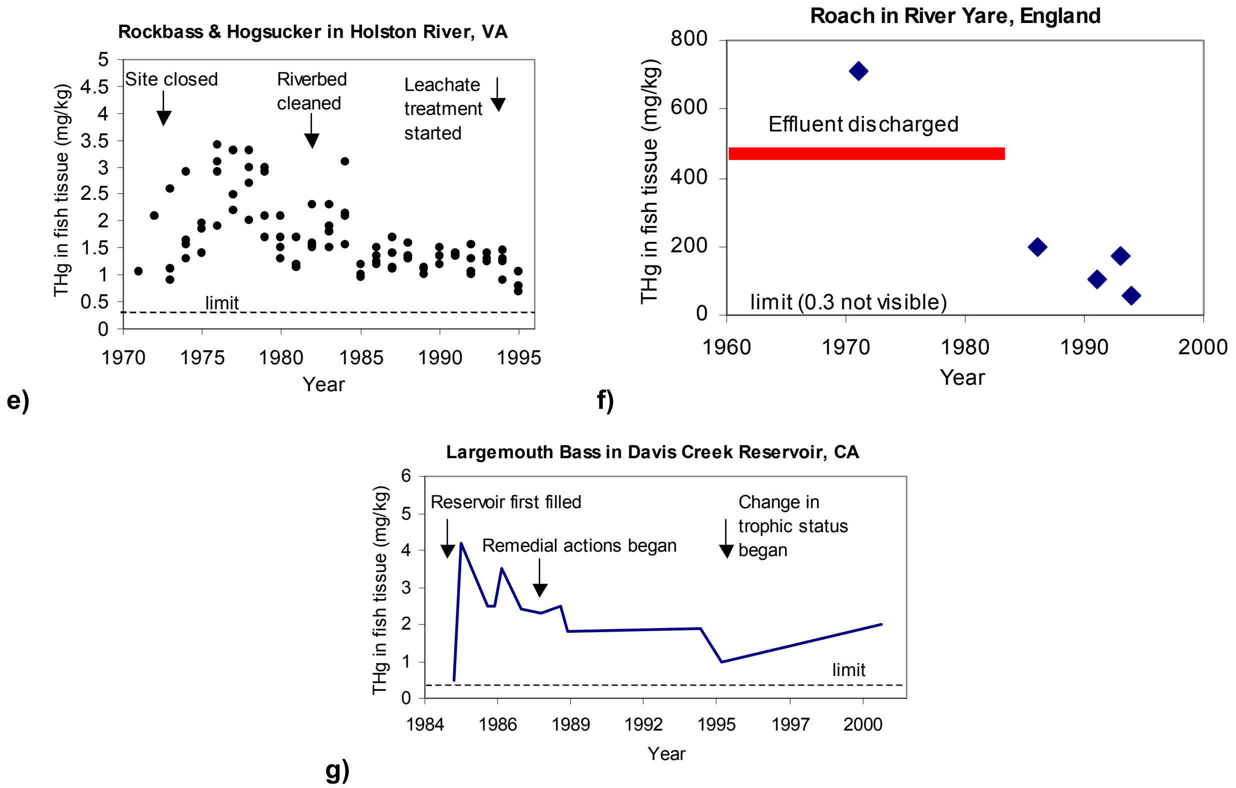

Figure 9. Time series of mercury concentrations in fish for remediated sites elsewhere in North America. All data shown is as total mercury except where noted. Sites are described in Table 2.

Table 4. Case studies of mercury remediation efforts in North America.

Waterbody	Source(s) Controlled	Control Measures	Effect & Time Period	References
Lake St. Clair, Detroit River – between Lake Huron and Lake Erie	Two chloralkali plants discharging several kg/day	"Aggressive" discharge treatment since 1970	Hg in walleye declined rapidly from 2.3 mg/kg (1970) to 0.5 mg/kg (1978), unchanged since 1994	1, Figure 9a
High Rock Lake, NC	Battery plant	Discharge treatment, groundwater remediation, soil removed from site	Load reduction 1981-1992, natural sediment burial in lake, lifted fish advisory in 1992	1
Poplar Creek, Oak Ridge, TN	Nuclear processing plant	Groundwater treatment, industrial pretreatment, soil treatment, runoff re-routed	Hg in sunfish (1983-1997) decreased from 1.5 to 0.6 mg/kg (5 km downstream), but increased 0.5 to 0.9 mg/kg 17 km downstream	2, Figure 9b
Pinchi Lake, British Columbia	Mercury mine site adjacent to lake (1940-1975)	Ended mining activity in 1975	Hg in fish declined from 10 mg/kg, but still exceed advisory level in 1995	1
Clear Lake, CA	Mercury mine site adjacent to lake (1850s-1957)	Mine closed in 1957; bank stabilization in 1992	Fish tissue concentrations (0.09-0.54 mg/kg for various species) have not changed since first monitored in 1970. Fish consumption advisory remains since that time.	
Davis Creek Reservoir, CA	Mercury mine (Reed) site in watershed (1860-1950, intermittently)	Reservoir constructed in 1985, closed to public (no fishing); Reed Mine cleanup and containment 1986-1999	In reservoir: Hg initially rose, then declined steadily	3, Figure 9g
Onondaga Lake, NY	Chloralkali plant (1947-1988) and other chemical plants discharging	"Better" regulation of all discharges since 1972; chloralkali plant closed in 1988	Initially rapid decrease of Hg in fish in early 1970s, but still >0.6mg/kg in 1992 for most sport fish	1, 4, Figure 9c
Clay Lake, English-Wabigoon River system, Ontario, Canada	Chloralkali plant and wood pulp mill	Plant closed in 1975	THg in water and sediments decreased, but MeHg increased; Hg in walleye decreased from 20 (1975) to 2 mg/kg (1990), then steadied at 2.7 mg/kg (1998)	1, 5, 6, 7, Figure 9d
Holston River, Saltville, VA	Chloralkali and other chemical plants	Plant closed in 1972, 600-m of river sediment dredged and grouted in 1976, site seepage treated in 1995	Hg in fish increased (1970-1975) while water quality generally improved; reduced from ~3 (1970) to 0.9 mg/kg (1995); 0.2 mg/kg considered background	1, Figure 9e
South River, VA	Industrial facility (1930-1940)	Plant closed in 1950	Sediment contaminated for 160 miles downstream found in 1983; Hg in sunfish 0.7 mg/kg in 1983, 1.4 mg/kg in 1997	1
Berry Creek, NJ (estuarine)	Hg processing plant (1930-1974)	Facility closed in 1974	Sulfide-rich marsh reduced Hg bioavailability, but Hg in fish and shellfish increased from 1979 to 1989	1
Lavaca Bay, TX (estuarine)	Chloralkali plant (1966-1979)	Discharges greatly reduced in 1970, site razed in 1985	No change of Hg in fish 1977-1999	1
Bellingham Bay, WA (estuarine)	Chloralkali plant (1965-1970)	Soil removal, groundwater treatment	Hg in sediments decreased (halved every 1.3 years) by sediment mixing dilution, flux from anoxic sediments significantly greater than from oxic sediments	1
Howe Sound, Squamish, British Columbia (estuarine)	Chloralkali plant (1965-1994)	Plant closed in 1994	Dungeness crab Hg decreased initially 4from 2 mg/kg in 1970 to 0.2 mg/kg in 1975, but no subsequent change	1
River Yare, England	Wastewater discharges (1964-present)	Reduced Hg load 26-fold in 1984	Total and methyl Hg in water at background levels by 1994, THg sediment concentrations decreased from 5.4 (1986) to 2.1 mg/kg (1994) but still ~15 times above background, no change in methyl Hg in sediments, same body burden in eels compared to control site	8, Figure 9f

References:

1. Turner and Southworth (1999)
2. Southworth et al. (2000)
3. Homestake Mining Company (HMC) (2002)
4. Becker and Bigham (1995)
5. Parks and Hamilton (1987)
6. Rudd et al. (1983)
7. Latif et al. (2001)
8. Edwards et al. (1999)

Models for the Linkage Analysis

The present level of modeling effort for the SRW relies on an annual average mass-loading model of total mercury[36]. The next level of effort would be a multivariate regression analysis, as used at the national scale to evaluate mercury data collected by the NAWQA program (Brumbaugh et al., 2001).

More sophisticated numerical models have been considered but have not been developed or applied to date due to spatial complexities (e.g., combination of point and diffuse sources, localized water quality conditions impacting methylation) and temporal variability (ranging from rapid chemical transformations to long-term leaching from contaminated areas) in the system. These factors increase (a) data requirements, (b) uncertainty on the modeling output, and (c) the level of effort requiring financial resources.

Models useful for predicting effects of specific actions in tributary watersheds are described here. See Appendix 4 for a complete discussion of the model evaluation.

<u>Source Loading Models</u>

Many models are available to predict soil loss from contaminated sites. Such models would be useful in estimating mercury loads from contaminated sites both before and after soil stabilization controls.

USEPA has developed numerical models to simulate mercury air transport and deposition in both the 50 km near-field (Industrial Source Complex 3 model, or “ISC3”) and across the U.S. (RELMAP, as discussed earlier) (Keating et al., 1997). These models can provide estimates of mercury mass deposition rates in the SRW as inputs to a watershed model. Additional regional air deposition data is required to support use of this modeling tool.

<u>Lake Model</u>

MERC4 is a generalized mercury transport, speciation, and kinetics model. It was developed for application to a variety of sites experiencing mercury contamination including ponds, streams, lakes, and estuaries (Martin, 1992). This model could be used in specific areas of the SRW, given adequate local data to support its use.

The Mercury Fate and Transport Model was used to track mercury in Clear Lake (Bale, 2000). The model covers the essential components of the conceptual model.

<u>Bioaccumulation Model</u>

One of the most sophisticated bioenergetics models available for use is the Bioaccumulation and Aquatic System Simulator (BASS) model (Barber, 2001). The simulation is designed to predict the population and bioaccumulation dynamics of age-structured fish assemblages, exposed to contaminants that bioaccumulate. This model could potentially be employed, in a linkage with other models (watershed, hydrodynamics, sediment transport, chemical equilibria), to represent mercury dynamics in the SRW.

<u>Delta Model</u>

DWR maintains the Delta Simulation Model II (DSM-II) for simulating the movement of water in the Bay-Delta, including the effects of tides on flows and salinity[37]. The HYDRO module simulates water movement (hydrodynamics). Output from that module can be used to run QUAL for simulating non-conservative water quality constituents. QUAL currently has significant limitation for simulating mercury as it does not allow for 1) time-varying fluxes from the sediment bed or the atmosphere, 2) transformations (e.g., methylation), 3) sediment transport, or 4) biological components (e.g., bioaccumulation).

Other modeling options to assess hydrodynamics and water quality changes in the SRW and Delta include the RMA (Resource Management Associates) suite of models[38], the Fischer Delta model[39], and USGS’ Delta model. Each of these models has been used successfully to simulate hydrodynamics and

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[36] The model was used to quantify source loads discussed in response to Question 2a.

[37] DSM-II documentation and downloads can be found at http://modeling.water.ca.gov/.

[38] See http://www.rmanet.com/models.htm.

[39] See http://www.flowscience.com/page7.html.

particle tracking in the Delta. Only the RMA models are capable of sediment transport simulation, which would be an essential component in the simulation of mercury dynamics in the SRW.

Systems Models
One of the most complex and comprehensive descriptions of watershed runoff is Hydrologic Simulation Program-FORTRAN (HSPF). HSPF is a collection of numerous mechanistic process models describing watershed hydrology, surface water quality, soil and groundwater contaminant runoff, and pollutant decay and transformation (Bicknell et al., 1993). It does not include methylation or any biotic components.

As an alternative, the general-purpose version of WARMF (Watershed Analysis Risk Management Framework) Version 5.5 is available[40] to design and evaluate watershed management alternatives. The river basin model links land catchments, rivers, and reservoirs. WARMF also does not include any mercury transformations or biotic components.

The Everglades MCM model is being developed as an ongoing component of research in the Everglades. EMCM covers the essential components of the conceptual model, although it was initially designed only for lake environments.

Identified Knowledge Gaps

In the course of answering the management questions, the knowledge gaps presented in Table 5 were identified. The remainder of this Plan recommends actions both to reduce mercury risk now and to address these knowledge gaps through additional study.

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[40] See demonstration at http://www.systechengineering.com/warmf.htm.

Table 5. Knowledge gaps in the mercury linkage analysis.

Element	Description	Knowledge Gaps
1	Mercury sources to the environment	o Atmospheric deposition rates and sources o Native soil content o Loads from mineral springs o Disposition of gold and mercury mine tailings o Effectiveness of source reductions
↓ *Linkage:*	*Natural and managed processes regulating mercury mass loading to aquatic systems near mercury sources*	
2	Mercury in water near sources	
↓ *Linkage:*	*Physical, chemical and biological transport, transformation, and entrapment processes on total mercury in the aquatic system during transport from sources to areas of methylation and biological uptake of methylmercury into food webs supporting target species*	o Methylmercury loading rates from tributaries o Loads from Putah Creek and agricultural drains o Reservoir effects on transport o Effectiveness of site remediation
3	Ambient total mercury and methylmercury in water and sediment at locations where biomagnification to fish species of concern occurs	o Relative bioavailability of source types
↓ *Linkage:*	*Biomagnification into target species as a function of ambient mercury concentrations in water and sediment and entry of methylmercury into food webs supporting target species*	o Water quality factors affecting methylation, bioaccumulation, and biomagnification rates
4	Mercury in fish tissue	o Data for Cottonwood and Thomes Creeks, many Sierra reservoirs
↓ *Linkage:*	*Exposure to humans and wildlife from consuming fish*	o Food chain relationships o Fish consumption patterns by humans and wildlife
5	Risk to fish consumers (human populations and sensitive wildlife) due to methylmercury in fish tissue	o Exposure levels and demonstrated effects of mercury in humans and wildlife

Fundamental Question 3 – What is a prudent course of action to reduce mercury risk in the SRW?

An adaptive management strategy is appropriate for this Plan given the magnitude of the problem, the long-term commitment required, the uncertainties, and the information gaps. Accordingly, the planning effort focuses on the identification and implementation of long-term solutions to the problem, while recommending near-term activities and objectives. This strategy includes reduction of sources and of factors controlling mercury bioaccumulation. The basic concepts of the Plan's recommendations are to:

- ☐ Identify appropriate areas for and types of pilot remediation projects;
- ☐ Develop a modeling framework for incorporating quantified relationships, assessing monitoring data, and improving predictive ability;
- ☐ Design and implement monitoring to assess local and regional effect of pilot projects and to support models;
- ☐ Design and perform research projects to reduce uncertainties in the linkage analysis and to improve models, and stay informed of and coordinate with other ongoing research projects;
- ☐ Develop and implement an outreach program to collect additional fish consumption information and to inform and educate affected people regarding mercury risks in the short term; and
- ☐ Continuously plan and evaluate progress.

In short, these concepts follow the approach shown generically in Figure 1, with specific activities replacing the generic elements (Figure 10). The recommendations are listed in each section from highest to lowest priority. Time frames are included with each recommendation to put into perspective a realistic and appropriate schedule and logical sequence for activities to proceed. General costs associated with each recommendation are enumerated. Success criteria for measuring progress are also provided.

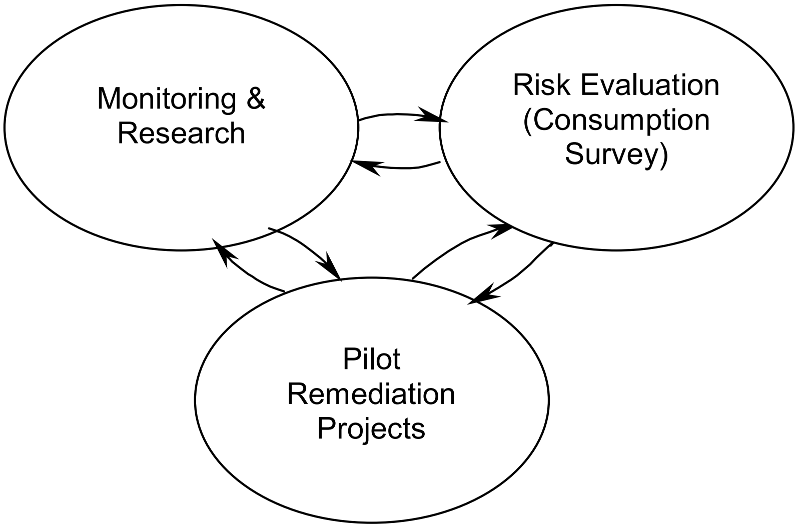

Figure 10. Basic elements of the strategic planning process. The elements as show in Figure 1 are now in terms of specific actions to address each element of the Plan.

Pilot Projects Plan

A critical step in reducing mercury contamination in fish in the SRW is identifying actions that could potentially result in a reduction in bioavailable mercury to fish, and which could serve as pilot projects to evaluate their effectiveness. Source controls (as opposed to reductions elsewhere in the linkage) have not been found to be effective at reducing mercury concentrations in contaminated areas to below target levels. While this Plan does not recommend specific pilot projects for reducing mercury risk, it does articulate a strategy for identifying them.

There have been measurements of fish tissue levels of mercury by the SRWP, USGS, and CALFED at stations throughout the SRW and Delta, but there has not yet been a watershed-wide assessment of actual mercury concentrations in fish tissue for all fished waterbodies[41]. Until these data become available, an estimate of mercury contamination based on understood relationships is a reasonable substitute for determining how and where to reduce this contamination.

Risk of high methylmercury concentrations in water and sediments, the presence of a mercury-prone fishery, consideration of land ownership, legal liability, and physical logistics are all considerations in selecting good places to test control measures that may reduce mercury in fish in the SRW. A team of engineers and environmental scientists within the DTMC have developed a “decision-support tool” (DST) to approach this task, using a computer program called “Ecosystem Management Decision Support” (EMDS), which relies on a knowledge base created by the user (see Appendix 5).

The goal is that the EMDS knowledge base contains the best scientific information available about how mercury accumulates in fish and thereby poses a health risk to humans and wildlife. In the EMDS system, the knowledge base is attached to spatial data describing areas in the SRW where factors contributing to mercury contamination of fish are present and where opportunities to reduce it are available. For example, the best area for a pilot remediation project is one where:

- ☐ *Implementation is feasible.* – Project feasibility is based on consideration of physical logistics of the project, legal opportunities and constraints, and the relative cost of remediation.
- ☐ *The area poses a relatively high risk to health.* – Risk to human and wildlife health due to mercury contamination in fish is based on the location of mercury sources, likelihood of methylation, and catching of fish that are likely to be contaminated.
- ☐ *The impacts of the project will be measurable.* – The ability to measure success is based on the type of remediation project, the nature of the site, the contribution of other sources, and the ability to estimate reductions in parameters of interest.

The following list summarizes the information important for developing the DST to prioritize specific project *areas*. It is the “knowledge base” which drives the system. Information not yet available is shaded.

I. Implementation of Project
    A. Cost of Remediation
        1. Type of Project (Potential Type of Remediation Activity)
    B. Legal Constraints
        1. Ownership (Private, Ownership Complexity)
        2. Downstream waterways on 303(d) List
    C. Logistics of Carrying out Project
        1. Land Use
        2. Physical Logistics (Steepness, Accessibility)
II. Chance of Measuring Impact of Remediation (fewer sources in smaller areas are best)
    A. Load of Hg/watershed area/# potential sources
    B. Concentration of Hg/watershed area/# potential sources
    C. Concentration of MeHg/watershed area/# potential sources

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[41] Such a study is presently being considered for funding by CALFED.

III. Contribution to Risk of Exposure to Mercury in Fish in Watershed
  A. Bay-Delta
    1. Consuming of Certain Fish
    2. Risk of Hg in Fish
      a. Actual Measured Hg (i.e., Measured Hg in Biota, Mercury in Benthos, Methylmercury in Water)
      b. Potential Sources of Hg (i.e., Tributaries, NPDES Dischargers, Mines, Atmospheric Deposition, Benthic Sediments)
      c. Risk of Methylation
        i. Suitable Site (i.e., Wetlands)
        ii. Water Quality (i.e., Sulfur Compounds, Nutrients, Suspended Sediment, Dissolved Organic Carbon, Temperature, Dissolved Oxygen, pH, Primary Productivity)
  B. Sacramento River Mainstem and Tributaries
    1. Consumption of Certain Fish
    2. Risk of Mercury in Fish
      a. Actual Measured Hg (Measured Hg in Biota, Methylmercury Load, Methylmercury Concentration)
      b. Mercury Sources
        i. Potential Sources of MeHg (NPDES Dischargers, Benthic Sediments, Mineral Springs, Atmospheric Deposition, Soil Erosion, Mercury Mines, Gold Mines)
        ii. Mercury Source Indicators (THg/Total Suspended Sediment, Total Mercury Load, Total Mercury Concentration)
      c. Risk of Methylation
        i. Suitable Site (Wetlands[42], Reservoirs)
        ii. Water Quality (i.e., Sulfur Compounds, Nutrients, Suspended Sediment, Dissolved Organic Carbon, Temperature, Dissolved Oxygen, pH, Primary Productivity)

EMDS was used to run several scenarios considering the information available. In each scenario a part of the knowledge base was represented differently in the model. Because of the possibility of “Good Samaritan” legislation in the future, private ownership was considered prohibitive to conducting projects in two scenarios and as having an unknown/neutral effect in two other scenarios. Similarly, because of incomplete knowledge about the various factors affecting rates of methylation (and therefore amounts/concentrations of methylmercury available for bioaccumulation) “risk of methylation” was included in two scenarios and excluded in two others.

The products of these four different versions of the knowledge base are shown in Appendix 5. Map 8 shows the distribution of areas in the watershed that best fit the various criteria including “risk of methylation” but excluding land ownership. The darker orange indicates a generally high suitability for pilot remediation projects and associated monitoring. Results highlight areas in the Pit River watershed (upper right area) and lower Bear River watershed (bottom central area) to focus on for reducing risk of mercury contamination in fish. Data for mercury concentrations in biota, sediment, and water in the Cache Creek watershed were not available to the authors at the time of the scenario development.

Once potential areas for remediation projects are adequately prioritized, the next level of use of the DST will be to prioritize specific project *sites*. For prioritizing specific project sites, the same types of information as shown would be necessary, but at the site level. Specific data needs will include unit costs of various control measures, estimated mercury load, and actions required. The pale circles in Map 8 indicate the location of ongoing or proposed remediation projects. The mine sites (the majority of circled sites) have been identified and prioritized previously (CDOC, 2000). Examples of remediation projects shown on the map are noted in the side box.

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[42] Currently the model assumes all wetlands are equally capable of methylation.

Pilot Project Recommendation 1 (Time Frame = 1-10 years, Cost = $200K): Provide for reasonable control of ongoing mercury sources by facilitating and enhancing programs by the State Water Resource Control Board (SWRCB) and Central Valley RWQCB to collect and dispose of mercury collected in gold mining regions. With continued support, more use of this program by small-scale dredge miners could result in direct removal of aquatic mercury in heavily contaminated waterways. Work should focus on watersheds highlighted by the DST.

Examples of Current Source Control Projects in Areas Highlighted by the DST

Most Suitable (Based on DST Results)

- *Boston Hydraulic Pit, South Fork Greenhorn Creek – Fish tissue mercury concentrations are high in downstream Rollins Reservoir. The settling pond, inlet, and outlet to the drain tunnel of this former gold mine are all contaminated with mercury. An inter-agency group (BLM, USFS, the watershed group, and private landowners) proposes clean-up action. The remediation project would be a learning experience for multi-stakeholder cooperation, as well as for the technical aspects of mercury removal from a hydraulic gold mining site.*
- *Sailor Flat Hydraulic Mine, Tahoe National Forest – 3-acre (=1.2 ha) site drains into an unnamed tributary of Greenhorn Creek. Non-time-critical removal action options are to excavate and fill or isolate and plug draining areas.*

Suitable (Based on DST Results)

- *Cache Creek Flood Control Project, City of Woodland – The Cache Creek Settling Basin is designed to trap sediment in Cache Creek, reducing the amount that enters the Yolo Bypass. In conjunction with a proposed flood control project, it would be possible to raise the basin levees, increasing storage capacity and removing a greater fraction of (mercury-laden) suspended sediment.*
- *Putah Creek watershed – Three mercury mines in the Putah Creek watershed (Helen, Research, and Chicago) are being investigated for remediation. The sites each have mercury retorts and large volumes of tailings. They are all located in Dry Creek Canyon, on land managed by the US Bureau of Land Management.*

Pilot Project Recommendation 2 (Time Frame = 0-5 years, Cost = $100K): Address legal liability issues on a project-specific basis. It is recommended that DTMC and other parties work with legal counsel from the SWRCB, USEPA, and other key agencies to explore legal approaches which will avoid legal liabilities and create incentives for implementation of a variety of mercury remediation project types in California.

A concern exists that parties that implement a mercury control project could be liable for larger responsibilities under federal law. In the specific case of the Penn Mine cleanup in the Mokelumne River watershed, tributary to the Delta, the construction of impoundments by the State of California and East Bay Municipal Utility District (EBMUD) to reduce the impact of acid mine drainage from Penn Mine on downstream waters led to a determination by USEPA that the impoundments were equivalent to treatment units which required an NPDES permit. The ensuing court case held that the State and EBMUD were responsible for full compliance with the Clean Water Act as an NPDES permittee, regardless of other good intentions associated with the cleanup project. This led the State and EBMUD to dismantle the facility they had constructed. The repercussions from this case have led to a broadened belief that other cleanup projects at mine sites will lead to unanticipated legal liabilities under the Clean Water Act, Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), or other federal laws. In the wake of the Penn Mine decision, California passed the Acid Mine Drainage Remediation Act, which provides protection for "Good Samaritans" who cooperate with a public agency (e.g., State Water Resources Control Board) to implement an approved remediation plan for an abandoned mine. The provisions of this act do not provide any exemption or immunity from the requirements of federal law, however.

The challenge is to identify and craft remediation projects that do not invite the federal response seen in the Penn Mine Case. Recently adopted USEPA regulations pertaining to coal mining operations at abandoned sites (40 CFR Part 434) appear to establish a positive precedent under federal law. These regulations create a distinction between pre-existing discharges and new discharges in which NPDES effluent limitations for a new mine operator would be based on the pre-existing baseline conditions rather than on compliance with water quality standards. These considerations would be made in exchange for performance of a pollution abatement plan to reduce pre-existing discharges. A similar approach, applied to abandoned mercury or gold mining operations, would likely remedy the problems encountered in the Penn Mine case.

Pilot Project Recommendation 3 (Time Frame = 1-10 years, Cost = $300K): Evaluate and characterize planned site remediation projects sufficiently to determine effectiveness of the remediation. During project design, ongoing efforts by the California Department of Conservation (CDOC) to characterize mine sites using satellite imagery should be evaluated for application[43]. Some work is ongoing in the Cache Creek watershed under funding provided through CALFED to assess control measure feasibility and effectiveness at abandoned mercury mine sites. Pilot projects need to include these basic components:

- *Estimate mass fluxes (Linkage 1→2)* – Measure flux rates to the atmosphere and to waterways (from estimates of soil erosion rates, groundwater flow, and mercury content in local soils). Estimate the mercury mass removed from (or contained on) the site by the remedial action and the mass expected to remain on site (and future flux rates).
- *Characterize mine waste and costs of removal/stabilization (Element 1)* – Use techniques such as “extended x-ray absorption fine structure” (EXAFS) to quantify mercury speciation in waste materials (Kim et al., 1999). Sites or areas on sites with more reactive fractions should be prioritized higher for remediation. Projects should keep track of the costs associated with specific activities to inform cost estimates for future projects.
- *Monitor mercury in biota (Element 4, Linkages 1→4)* – Measure mercury concentrations in local biota to establish baseline and post-project conditions. Frequency and intensity of monitoring should be based on a power analysis to provide assurance of measuring success.

Pilot Project Recommendation 4 (Time Frame = 1-10 years, Cost = $200K): Continue to develop and to support the DST as information becomes available from ongoing monitoring and research activities to prioritize areas suitable for remediation. In addition to the current version of this tool, future versions could be developed to identify project waterways (for example, for identifying the best sites to reduce methylation and bioaccumulation) or to compare specific project sites. The EMDS approach means that geographic information system (GIS)-based maps of the SRW and decision rules can be updated easily as new data becomes available, or as more is learned about mercury transport, transformation, and accumulation. This approach also helps to show where we lack sufficient data and knowledge to make certain assessments or decisions. Additional data and knowledge needed to fulfill requirements of the DST are shaded in the DST knowledge base list (above).

CALFED-funded studies on mercury and methylmercury loads and transformations to the Yolo Bypass and Delta and on a methylmercury budget for Delta waterways should be followed.

Success Criteria for Pilot Projects Plan

Success of the pilot project recommendations in meeting the objective of the Strategic Plan will be judged based on the following:

- Existing programs to collect mercury from individual miners continued, collecting mercury in the American, Yuba, and Feather Rivers’ watersheds.

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[43] See http://www.consrv.ca.gov/radar/geosar/year2rpt/chap2_4.html.

☐ A land remediation project has occurred on private land, with minimal legal obstacles.

☐ Remediation sites were characterized sufficiently to calculate the mercury mass flux, speciation, and concentrations in local biota. USEPA's Preliminary Remediation Goals[44], indicating threshold concentrations of pollutants in soils, should be used during initial screening-level evaluations to help identify areas or contaminants that do not require further federal attention.

☐ The DST has been maintained and was used to select project sites.

For BMP or remediation effectiveness monitoring, the level of effectiveness ("reliability") should reflect realistic goals of the specific project (e.g. 25-50% reduction in loads), with a statistical confidence level of 90-95%, and statistical power (the probability of detecting a "true" effect) of at least 80%. Creel surveys and fish consumption surveys should be designed to provide estimates within <10% of the "true" value (e.g. the percentage of population consuming greater than 35 g of white catfish per week, or the number of largemouth bass caught per unit effort) at a confidence level of 95%.

Modeling Plan

The modeling plan serves as a guide for research (to fill gaps in quantifiable relationships), monitoring (to calibrate and test simulation results), and pilot project evaluations (comparing project options based on model results). Modeling efforts should be approached judiciously, given the substantial costs of modeling. In some cases, the level of scientific understanding is not yet sufficient to construct defensible process-oriented models. A watershed level model is not the initial goal and public domain models are recommended, when available.

Modeling Recommendation 1 (Time Frame = 0-5 years, Cost = $100K): Use multivariate regression analysis to prioritize factors affecting methylation and bioaccumulation.

Modeling Recommendation 2 (Time Frame = 0-5 years, Cost = $250K): Use a peer reviewed, public domain model to simulate potential effects of remediation at Clear Lake (Elements 1 to 4, Linkages 2→4). Clear Lake has been and will continue to be the focus of intensive research. Because the potential effects of reducing mercury loads from the Sulphur Bank Mercury Mine are still undetermined, the body of research for Clear Lake could be used to develop, calibrate, and validate a sophisticated model separate from the watershed model. The lake model should include linkages from sources to sport fish, be time-varying, and include spatial gradients.

Modeling Recommendation 3 (Time Frame = 1-10 years, Cost = $700K): Focus simulation modeling on a watershed tributary to the larger SRW, in collaboration with remediation activities. The primary value of such a model would be the identification of various source loading areas and source types (Elements 1 and 2). Management scenarios such as source reduction, dam removal, and methylation reduction could be explored (Linkages 1→3). A watershed model should be applied in conjunction with a mercury-reduction watershed project. Erosion processes are basic components of existing models and will not need improvement. Existing models will require improvements in their linkage analysis to appropriately simulate the path of mercury from sources to biota.

More site-specific quantification of mercury source loads and speciation will be required to extrapolate diffuse-source loads watershed-wide. The watershed model should track total and methylmercury in water and sediments. A sediment transport model is a necessary component of any mercury transport model, because almost all mercury is adsorbed onto sediments. The Englebright Dam removal study currently underway will explore modeling options for this component.

Large-scale (i.e., watersheds for major tributaries) atmospheric deposition estimates should not rely on RELMAP results until monitoring within the SRW indicates that those values are reasonable. Site-scale atmospheric transport could be modeled using ISC3, although this would require additional data collection (i.e., sediment-air flux rates and transformation rates in air) to aid in quantifying source loads by mercury species.

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[44] Posted with explanation at http://www.epa.gov/region09/waste/sfund/prg/index.htm

Development and implementation of a model capable of simulating mercury movement through the entire SRW is not recommended at this time because it would require an overwhelming investment of personnel and monetary resources. Water transfers (mainly pumping and diverting for agriculture and water supply) from the Sacramento River and tributaries complicates the development of a mercury model for the entire SRW.

Modeling Recommendation 4 (Time Frame = 1-10 years, Cost = $200K): Use a statistical bioaccumulation model as a first step in applying results of a watershed model to predict effects on biota (Elements 3 and 4, Linkage 3→4). Once this level of effort has provided preliminary information to direct a more detailed study, the model BASS is recommended for simulating the linkages between mercury species in water and sediment, and in consumed fish. To develop a bioenergetics model, data will need to be collected to relate ambient mercury concentrations to mercury concentrations in low trophic level species, and from low trophic level species to fish species caught and consumed by anglers. It is not recommended to incorporate a sophisticated bioaccumulation model directly into a watershed or Delta model.

Success Criteria for Modeling Plan

Success of the modeling recommendations in meeting the objective of the Strategic Plan will be judged based on the following:

- ☐ A multivariate regression analysis has been conducted to prioritize water quality and watershed factors that appear to impact mercury concentrations in fish.
- ☐ Numerical models have been evaluated and the “best” one chosen to simulate remediation effects in Clear Lake.
- ☐ Numerical models have been evaluated and the “best” one chosen to simulate the effects of a remediation project in the SRW.
- ☐ A statistical model of mercury bioaccumulation has been developed based on existing data.

Monitoring Plan

Monitoring is a critical part of the process of improving the linkage analysis, evaluating remediation effectiveness, and understanding the distribution and risks of mercury. To address the management questions, the DTMC will use SRWP monitoring data 1) to establish baseline water quality conditions and fish tissue concentrations in the SRW for assessing the effectiveness of management actions, and 2) to support development of risk assessment models and better quantitative models for mercury transport and bioaccumulation.

It should be anticipated that changes at downstream locations would have to be tracked for at least ten years to see effects of any remediation project. This time frame is stated to reinforce the notion that changes in mercury levels in the SRW will not come quickly, since there are no major point sources. Furthermore, proposals for control could potentially cause an opposite effect: cause an increase in fish mercury by mobilizing sedimentary mercury or enhancing conditions for methylation. The pilot study approach – doing small projects with good probability of success and monitoring for effectiveness – is the preferred approach. At this point, there is no conclusive evidence *not* to monitor total mercury in addition to its various species. It is also important that remediation and solution must be tested in a reasonable subset of cases by effective monitoring.

Monitoring Recommendation 1 (Time Frame = 0-20 years, Cost = $1,000K): Monitor mercury concentrations (total, methyl, and inorganic in water; methylmercury in fish tissue) at integrator sites[45] where fishing intensity (or consumption, once information is available) is high (Elements 2 to 4). Monitoring at stations lower in the watershed should continue to provide a useful long-term dataset of baseline conditions. Cottonwood and Thomes Creeks and many reservoirs in the Sierras warrant initial measurements of mercury in fish tissue to compare levels there to other tributaries and to criteria.

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[45] Integrator sites are those that represent the integrated effect of many distinct areas, such as Sacramento River at Freeport.

Augment standard water column monitoring for mercury and methylmercury at four (or more) mainstem sites with the following: [Hg] and [MeHg] in bedded and suspended sediments, including particulate and pore water concentrations; methylation/demethylation rates in bedded sediments; grain size analysis; photodegradation rates; [Hg] in phytoplankton, invertebrates, and lower trophic level fish; tissue isotope analysis in invertebrates and fish; temperature; sulfates and other nutrients; and any other potentially important parameters for methylation, demethylation, and biouptake processes. Sediment monitoring should consider spatial variation in the stream channel (e.g., margins vs. mid-channel differences).

Current and future (already planned and funded) water quality monitoring stations were shown in Map 4. Programs responsible for the monitoring stations are noted in Table 6.. On the scale of the entire watershed, sufficient data will be collected through these existing and planned efforts to assess watershed-wide loading rates over the next few years. CALFED-funded studies (one being completed in 2002; two starting in 2002) by the San Francisco Estuary Institute to measure mercury in sport fish in the Delta also should be followed.

Monitoring Recommendation 2 (Time Frame = 1-15 years, Cost = $2,000K): Monitor the effectiveness of source control (Element 1, Linkage 1→2) and other environmental manipulations, in collaboration with planned pilot remediation projects. A diverse suite of source control projects of different types and in different locations should be monitored to quantify effectiveness of selected control measures (i.e., pre- and post-project monitoring). Control strategies should be evaluated in carefully conceived and monitored pilot studies before being implemented on a large scale. Monitoring analytes should include total and methylmercury in water and sediments, methylmercury in biota, as well as other constituents and conditions that may affect speciation, methylation, or bioaccumulation rates (e.g., temperature, nutrients, carbon, pH, sulfur anions, TSS, and dissolved oxygen), upstream and downstream of the project site. Monitoring young-of-the-year fish serve to integrate food web effects and accumulation of HgII, thus being a better indicator than invertebrates. Sampling frequency should be no less than monthly for water quality constituents, and quarterly for fish and surficial sediments at multiple stations[46]. If a project is financially incapable of supporting a rigorous sampling program, parties need to recognize that the rare opportunity to fill this knowledge gap (e.g., address effectiveness of a given control measure) will be lost.

Success Criteria for Monitoring Plan

Success of the monitoring recommendations in meeting the objective of the Strategic Plan will be judged based on the following:

- ☐ Long-term funding has been found and used to set up an initiate a monitoring program at integrator sites in the SRW.
- ☐ Indicator sites have been selected and monitored, with a plan to collect sufficient data to evaluate effectiveness of remediation.
- ☐ Source control measures implemented in the SRW have been monitored for effectiveness.
- ☐ Bioaccumulation control measures implemented in the SRW have been monitored for effectiveness.

Linkage Analysis Research Plan

Concerns for mercury accumulation in fish tissue continue to prompt considerable research around the world. Research needed to better understand the fate and transport of mercury in the SRW are described here. In addition to these recommendations, CALFED is developing a research strategy for mercury in the SRW. The results of that process will be coordinated with this section as much as possible[47]. Ongoing research led by USGS is aiming to identify mercury pathways in ecosystems as well as determine which mercury is bioaccumulating in food webs[48].

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[46] The Everglades ecosystem assessment project utilized 200 canal stations and 750 marsh stations.

[47] CALFED draft project reports will be available mid-2002; the CALFED strategic plan will be developed in late 2002.

[48] See http://infotrek.er.usgs.gov/mercury/.

Table 6. Mercury Monitoring in the Sacramento River Watershed (Ongoing and Planned).

		Mercury in Water				Mercury in Sediment					Mercury in Biota (& metals and organics in fish)						
Location	Agency/ Programs monitoring @ location	Total Hg, unfiltered	Total Hg, filtered	MeHg, unfiltered	MeHg, filtered	Total Hg	MeHg	lead-210	%Carbon	Sed-H20 Flux	Hg in Fish	OCs in Fish	Metals in Fish	Hg in Benthic Inverts	Hg in Amphibians	Hg in Shellfish	Avian repro (Hg in eggs)
Pit R. above Shasta																	
McCloud R. above Shasta																	
Sac. R. above Shasta	SRWP										SRWP-1						
Spring Ck. PP Discharge																	
Sac. R. b/ Keswick	SRWP, RED, DWR	SRWP-5 RED-12 DWR-12	SRWP-5 RED-12	SRWP-5 DWR-12+e	SRWP-5 DWR-12+e						SRWP-2						
Boulder Ck	DWR	DWR-12+e		DWR-12+e													
Clear Ck nr Igo	DWR	DWR-12+e		DWR-12+e													
Churn Ck	DWR	DWR-12+e		DWR-12+e													
Stillwater Ck	DWR	DWR-12+e		DWR-12+e													
Cow Ck near Millville (gage)	DWR	DWR-12+e		DWR-12+e													
Cow Ck (multiple sites)	SRWP																
Ash Ck	DWR	DWR-12+e		DWR-12+e													
Cottonwood Ck nr Cottonwood (gage)	DWR	DWR-12+e		DWR-12+e													
Battle Ck d/s Coleman Hatchery (gage)	DWR	DWR-12+e		DWR-12+e													
Sac. R. @ Balls Ferry	DWR	DWR-12+e		DWR-12+e													
Sac. R. above Bend Br	SRWP; DWR;	SRWP-9 DWR-12+e	SRWP-9	SRWP-9	SRWP-9						SRWP-2						
Paynes Ck	DWR	DWR-12+e		DWR-12+e													
Reeds Ck	DWR	DWR-12+e		DWR-12+e													
Red Bank Ck	DWR	DWR-12+e		DWR-12+e													
Sac. R. d/s Red Bluff Diversion Dam	DWR	DWR-12+e		DWR-12+e													
Elder Ck	DWR	DWR-12+e		DWR-12+e													
Antelope Ck	DWR	DWR-12+e		DWR-12+e													
Mill Ck nr Molinos	SRWP, DWR	SRWP-9 DWR-12+e	SRWP-9	SRWP-9 DWR-12+e	SRWP-9						SRWP-?						
Trib to be Determined (6 sites)	SRWP (DFG-SS)	SRWP-2e	SRWP-2e	SRWP-2e	SRWP-2e												
Deer Ck nr Vina (gage)	DWR	DWR-12+e		DWR-12+e													
Thomes Ck diversion	DWR	DWR-12+e		DWR-12+e													
Thomes Cr (@ mouth)	DWR	DWR-12+e		DWR-12+e													
Sac. R. @ Woodson Bridge	DWR	SRWP-2e DWR-12+e		SRWP-2e DWR-12+e	SRWP-2e												
East Park Res	DWR	DWR-12+e		DWR-12+e							DWR						
Stony Gorge Res	DWR	DWR-12+e		DWR-12+e							DWR						
Black Butte Res	DWR	DWR-12+e		DWR-12+e													
Stony Ck (multiple sites)	SRWP, DWR	DWR-12+e		DWR-12+e													
Stony Ck (at mouth)	SRWP, DWR	DWR-12+e		DWR-12+e							SRWP-2						
Glenn-Col. Canal d/s Stony Ck conf.	DWR	DWR-12+e		DWR-12+e													
Tehama-Col. Canal d/s Stony Ck conf.	DWR	DWR-12+e		DWR-12+e													
Big Chico Ck (multiple sites)	SRWP																
Big Chico Ck @ Mouth	DWR	DWR-12+e		DWR-12+e													
Sac. R. near Hamilton City	SRWP; DWR	SRWP-9 DWR-12+e	SRWP-9	SRWP-9 DWR-12+e	SRWP-9						SRWP-2						
Sac. R. @ Colusa	SRWP, NAQ, DWR, DPR	SRWP-9 NAQ-12 DWR-12+e	SRWP-9	SRWP-9 DWR-12+e	SRWP-9						SRWP-2						
Butte Ck (multiple sites)	SRWP, DWR																
Butte Ck. @ Gridley Rd.	DPR																
Main Canal @ Gridley Rd	DPR																
Cherokee Canal	DPR																

Table 6 (continued).

Gilsizer Sl. @ Obanion	DPR																
Gilsizer Sl. @ Bogue Rd.	DPR																
Butte Sl. @ Lower Pass Rd	DPR																
Wadsworth Canal	DPR																
Sutter Bypass @ Kirkville Rd	DPR																
Sacramento Sl.	SRWP, DPR	SRWP-9	SRWP-9	SRWP-9	SRWP-9						SRWP-2						
Colusa Basin Drain	SRWP, DPR	SRWP-9	SRWP-9	SRWP-9	SRWP-9						SRWP-2						
Bear River @ Wheatland	USGS, DPR	GS-12+1e		GS-12+1e													
Bear River (multiple sites)	USGS	GS		GS							GS			GS	GS		GS
Deer Ck (multiple sites)	USGS	GS		GS							GS			GS	GS		GS
Englebright Lk	USGS										GS						
Scott's Flat Res.	USGS										GS						
Rollins Lk	USGS										GS						
Combie Lk	USGS										GS						
Camp Far West Res	USGS										GS						
South Yuba R. (multiple sites)	USGS	GS		GS							GS			GS	GS		GS
Yuba R. @ Marysville	SRWP	SRWP-9	SRWP-9	SRWP-9	SRWP-9												
Yuba R. @ Simpson Ln	DPR																
Jack Sl. @ Jack Sl. Rd.	DPR																
Feather R. @ Yuba City	DPR																
Feather R. near Nicolaus	SRWP, DPR	SRWP-9	SRWP-9	SRWP-9	SRWP-9						SRWP-2						
Sac. R.Outfall, DWR Plant #1	DPR																
Sac. R. nr. Village Marina	DPR																
Sac. R. @ Veterans Br.	SRWP, CMP, DPR	CMP-12	CMP-12	CMP-12	CMP-12						SRWP-2						
Coon Ck/Auburn Ravine	SRWP (Placer Co RCD)																
Arcade Ck	SRWP, SAC (CF)	SRWP-9	SRWP-9	SRWP-9	SRWP-9												
Natomas East Main Drain	SRWP										SRWP-2						
American R. b/ Nimbus Dam	CMP	CMP-12	CMP-12	CMP-12	CMP-12												
American R. @ J St.	SRWP										SRWP-2						
American R. @ Discovery Pk	SRWP; CMP	CMP-12	CMP-12	CMP-12	CMP-12						SRWP-2						
Sac. R. @ Freeport	SRWP, CMP, NAQ	CMP-12 NAQ-12	CMP-12 NAQ-12	CMP-12 NAQ-12	CMP-12 NAQ-12												
Sac. R. @ RM44	SRWP, CMP	CMP-12	CMP-12	CMP-12	CMP-12						SRWP-4						
Sac. R. @ Greene's Lndg	SRWP, DWR (MWQI) CalFed (RWQCB)	SRWP-9 SRWP-2e CF-12	SRWP-9 SRWP-2e CF-12	SRWP-9 SRWP-2e CF-12	SRWP-9 SRWP-2e CF-12												
Yolo Bypass	CalFed (USGS)	CF-e		CF-e													
Cache Ck (multiple sites)	CalFed (UCD, USGS)	CF		CF							CF			CF			
Cache Ck @ Rumsey	CalFed (USGS)	CF		CF													
Clear Lake - Upper Arm	RWQCB	RB-2e	RB-2e	RB-2e	RB-2e	RB-6e +1core	RB-6e +1core	1core x60	1core x60	RB-24e				RB-1e			
Clear Lake - Lower Arm	RWQCB	RB-2e	RB-2e	RB-2e	RB-2e	RB-6e +1core	RB-6e +1core	1core x60	1core x60	RB-24e				RB-1e			
Clear Lake - Oaks Arm (3 sites)	RWQCB	RB-6e	RB-6e	RB-6e	RB-6e	RB-6e +1core	RB-6e +1core	1core x60	1core x60	RB-24e				RB-2e			
Clear Lake - Rodman Slough	RWQCB	RB-12e	RB-12e	RB-12e	RB-12e												
Clear Lake - Upper Arm Shoreline	RWQCB	RB-10e	RB-10e	RB-10e	RB-10e												
Cache Sl. near Ryers Ferry	SRWP										SRWP-2						
Putah Ck	CalFed (RWQCB)	CF		CF							SRWP-2						
Selected CA sites (SWAMP)	SWRCB (SB)	SB??				SB??					SB						
Random CA sites (few in SR w'shed)	EMAP	EMAP??				EMAP??					EMAP						
6 Bay Delta Sites	CalFed (TA&M)					CF	CF			CF-8							
SJR, Cosumnes R., Mokelumne R.	CalFed (RWQCB)	CF		CF		CF-?											
100 Bay-Delta Sites	CalFed (DFG)					CF	CF										CF
Delta and SF Bay	RMP, CalFed, DK	RMP-3	RMP-3			RMP					RMP, CF, DK					RMP	

Notes: Shaded entries indicate current (Year 3) SRWP monitoring

Cell entries indicate monitoring agency, number of samples per year, and sampling basis, e.g.:

"DWR-12" indicates Dept of Water Resources will collect and analyze 12 samples at the specified location.

"XXX-12e" indicates some or all samples are collected on a event-based schedule.

"XXX-6+3e" indicates 6 regular scheduled samples + 3 event-based samples.

"XXX-6s" indicates samples are limited to a specific season.

"XXX-6se" indicates event-based samples limited to a specific season

Suggested Waterways for Research and Monitoring

The following waterways are recommended for research and monitoring. Each waterway presents unique conditions, of which a better understanding would improve the linkage analysis.

- *Arcade Creek – High total and methylmercury concentrations (Element 3). No identified point sources (Element 1). Methylation potential may be related to urban land uses that increase eutrophication (Linkage 3→4).*
- *Sacramento Slough and Colusa Basin Drain – High total and methylmercury concentrations (Element 3). Potential sources include historical pesticide use, atmospheric deposition, re-entrainment of mercury-laden sediment deposits (pre-dam era), and mercury content in native soils (Elements 1-2).*
- *Putah Creek – Little aquatic mercury data reported (Element 2). More sampling during storm events and sample stations upstream of Lake Berryessa would provide comparative information for un-dammed Cache Creek, with a slightly higher biotic mercury accumulation (Slotton et al., 1999). Distinct from Cache Creek in that the mercury problem appears more widespread (Elements 1-4).*
- *Yuba River above, from, and below the Yuba Gold Fields – North America's largest active gold dredging operation today, processing over four million cubic yards of rock and soil annually, is located along the Yuba River near Marysville. It is possible that legacy mercury in this large (~10,000 acres) area is leaching into the Yuba River, which passes directly through it (Element 1-2, Linkages 1→3).*
- *Yolo Bypass – The seasonal nature of the flooding simulates (annually) a newly formed reservoir (Elements 2-3). Methylation rates are potentially high because of the wetland conditions (Linkage 3→4). Wildlife habitats there and in the downstream Delta are critical areas (Element 5).*
- *Sacramento-San Joaquin Rivers Delta – High methylation rates yet an overall loss of methylmercury in the Delta (Linkage 2→3). A coincident spatial trend of higher bioaccumulation in peripheral areas and lower bioaccumulation in the central Delta is also observed (Linkage 3→4). CALFED-funded research will determine if these conditions are dependent on inflow mercury forms, benthic mercury fluxes, other biogeochemical conditions, or food web pathways.*
- *Lake Natoma – Preliminary results indicate that mercury bioaccumulation in this artificial lake is high (Linkage 3→4). This area has sediments deposited from the gold mining legacy era and dredged subsequently (Elements 1 and 2). USGS proposes to analyze water, sediment, and biota to determine relative methylmercury exposure levels in the lake's three main tributaries (Linkages 2→3 and 3→4). Potentially differential effects of varying development and management practices in the drainages on localized exposure transport will be assessed.*

Source Loadings Research (Elements 1 and 2, Linkages 1→2 and 2→3)

Source Loadings Research Recommendation 1 (Time Frame = 2-5 years, Cost = $400K): Monitor wet and dry atmospheric deposition of mercury monthly in major depositional zones of the SRW and in the Delta for a minimum period of one year. Results should then be compared with RELMAP results for the same period and used to calibrate the model. Upwind (but within California) emissions should be accounted for to distinguish local from global sources. Atmospheric emission rates estimated by the California Air Resources Board should be reconciled with deposition rates.

CALFED is funding a study to monitor atmospheric deposition in the Delta. The METAALICUS research project should be followed for knowledge on the transport, transformations, and bioaccumulation of atmospheric mercury.

Source Loadings Research Recommendation 2 (Time Frame = 2-5 years, Cost = $100K): Collect soil samples from Central Valley and tributary watersheds with higher than average Hg:TSS ratios. Results will indicate the potential mercury load reduction from soil erosion protection activities (such as altered land use practices and bank stabilization). Samples collected in 2000 by the Kearney Foundation (University of California) should be analyzed. This research should include a component to quantify the potential of soil from various watersheds to methylate when transported to downstream receiving waterbodies.

CALFED-funded research projects being completed by Moss Landing Marine Laboratories and Texas A&M University on this topic should be followed.

Source Loadings Research Recommendation 3 (Time Frame = 2-5 years, Cost = $300K): Measure in-stream, reservoir, and riparian sediments. Funding a study to measure mercury in sediment cores in selected reservoirs throughout the watershed will provide a temporal history of mercury in sediments similar to that found in the Lake Tahoe basin (Heyvaert et al., 2000). Results of this effort would help to establish baseline conditions and to improve our knowledge of the fate of mercury used in hydraulic gold mining.

Source Loadings Research Recommendation 4 (Time Frame = 1-5 years, Cost = $200K): Measure total and dissolved mercury concentrations and other water quality parameters in waters emanating from representative mineral springs in the watersheds of Cache Creek, Mill Creek, and Pit River. Identify "signature" water quality parameters in mineral spring discharges that can be used as tracers for those inputs. Estimate the flow from mineral springs in these watersheds by measuring concentrations of these "signature" parameters at downstream stream gaging locations. Calculate loading estimates using the resulting concentration and flow information.

USGS is collecting additional data in the Bear-Yuba and Trinity River watersheds[49]. In particular, sediments above Englebright Reservoir were sampled in summer 2002 but analyses are not yet complete. The CALFED-funded study being completed in 2002 by USGS on load estimates to the Delta from Cache Creek and Yolo Bypass should be followed. Other CALFED-funded projects being completed in 2002 by CDOC and Frontier Geosciences on mine site characterization should also be followed.

Methylation and Bioaccumulation Research (Elements 2 to 4, Linkages 2→4)

Methylation and Bioaccumulation Research Recommendation 1 (Time Frame = 0-5 years, Cost = $200K): Quantify mercury mass fluxes (inflows and outflows; sediment and air; net methylation and bioaccumulation rates) through wetland environments as a function of environmental conditions.

CALFED-funded projects that address this linkage in the Delta (one being completed in 2002 by UC Davis and another starting in 2002 by the California Department of Fish and Game) should be followed.

Methylation and Bioaccumulation Research Recommendation 2 (Time Frame = 0-5 years, Cost = $200K): Study food web characteristics and interactions in Cache and Putah Creeks and in the Delta. Consider analyzing ^{13}C, ^{15}N and ^{34}S isotopes in fish tissue analyzed for mercury concentrations. This relatively inexpensive analysis was used successfully in the Everglades and can provide valuable information allowing better characterization of fish trophic levels and potentially of mercury sources.

Separate CALFED-funded projects completed in 2002 and awarded in 2002 for UC Davis to conduct bioaccumulation-based mercury monitoring for Cache Creek, Prospect Island and Adjacent Tracts, the Yolo Bypass, and Cosumnes River should be followed. Another CALFED-funded project starting in 2002 by USGS will track mercury emanating from Frank's Tract (a Coast Range tributary) and the Cosumnes River (a Sierra Nevada tributary) through the Delta environment up to sport fish, to quantify the important

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[49] See http://ca.water.usgs.gov/valley/dutch/, http://ca.water.usgs.gov/mercury/, http://ca.water.usgs.gov/projects00/ca553.html, and http://minerals.usgs.gov/west/projects/hgas.html.

processes driving bioaccumulation. Ongoing research by John Gunn (Canada) and Hans Hultberg (Sweden) on methylation and bioaccumulation should also be followed.

Risk Assessment Research (Elements 4 and 5, Linkage 4→5)

A risk assessment plan is recommended to improve the ability to quantify the effects of mercury contamination today and subsequent to remediation efforts. Additional research on the toxic effects and bioaccumulation of mercury is being conducted by USGS nationwide, including sites in Cache Creek and Sierra Nevada waterbodies[50].

Risk Assessment Research Recommendation 1 (Time Frame = 1-5 years, Cost = $1,000K): Conduct a fish consumption study to identify sensitive and highly exposed populations, and geographic areas within the watershed where these populations can be found. The DTMC is currently working with CALFED, Central Valley Regional Board, COEHHA, and the California Department of Health Services to design a fish consumption study and related outreach strategy within the SRW. Data obtained through Department of Fish and Game creel surveys and a Central Valley RWQCB database of fish tissue mercury concentrations are being used to structure an outreach program that will lead to the development of a larger survey and study to derive statistically sound data. DTMC, CALFED, and Central Valley RWQCB are funding the initial scoping and work planning phase of the study. Funding sources for future phases have not been identified.

The following are the recommended key objectives for a fish consumption study:

- ☐ Determine fish consumption patterns for target populations (i.e., high-rate fish consumers) in the Delta watershed, including the SRW and the San Joaquin River (this objective will need further refinement in subsequent discussions),
- ☐ Identify highly exposed and sensitive populations, pursuing other measures of exposure such as measuring mercury levels in hair and blood in high-risk individuals[51],
- ☐ Identify high priority areas (e.g., locations with high concentrations of anglers and high levels of mercury in fish),
- ☐ Identify knowledge gaps related to fish consumption and public education,
- ☐ Identify outreach and education needs,
- ☐ Develop and implement outreach and educational activities, and
- ☐ Use a participatory approach that involves stakeholders and local organizations.

Managers will be interested in information such as, "How many people might be consuming mercury in local fish at rates which exceed the USEPA RfD value, given different fish tissue concentrations (e.g., existing versus future target levels)?" and "What percentage reduction in this number of people will be achieved if we remediate to a given fish tissue concentration?".

Risk Assessment Research Recommendation 2 (Time Frame = 0-5 years, Cost = $200K): Continue to monitor local avian species exposure to mercury through random egg collections, nest box studies, and egg exposure (reproductive failure) assessments. Incorporate information about wildlife feeding habitats.

Recently awarded grants by CALFED to USGS (lab level) and the US Fish and Wildlife Service (field level) for this activity should be followed and evaluated when results are available[52].

Risk Assessment Research Recommendation 3 (Time Frame = 1-10 years, Cost = $200K): Conduct a Margin of Exposure (MOE) analysis of mercury in hair of women of child-bearing age in the SRW. The MOE analysis would consist of collection and analysis of hair samples from women in various population groups, including those believed to be most likely at risk due to high levels of local fish consumption. The mercury concentrations in these hair samples would be used to compare with the Benchmark Dose Level

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[50] See http://ca.water.usgs.gov/mercury/Bear-Yuba/ and http://ca.water.usgs.gov/projects00/ca553.html.

[51] Blood is a more accurate estimate of current mercury body burden; hair levels could be useful only if correlated with blood levels.

[52] One pair of grant projects is near completion; another set will start work in 2002.

derived by the NRC in the evaluation of the USEPA reference dose (12 parts per trillion mercury in maternal hair). These results will be compared to data collected near Clear Lake. COEHHA recognizes the lack of data on levels of mercury in human blood and other tissues in their Environmental Protection Indicators for California Program[53].

Success Criteria for Linkage Analysis Research Plan

Success of the linkage analysis research recommendations in meeting the objective of the Strategic Plan will be judged based on the following:

- ☐ Wet and dry atmospheric deposition rates of mercury in the SRW and Delta have been measured.
- ☐ Soil samples from Central Valley and tributary watersheds with higher than average Hg:TSS ratios have been collected, analyzed and reported.
- ☐ In-stream, reservoir, and riparian sediments in SRW waterways have been measured for total and methyl mercury concentrations.
- ☐ Mercury loads from mineral springs in Cache Creek and Mill Creek watersheds have been estimated.
- ☐ Wetlands (including the Delta) have been researched to quantify mercury mass fluxes and cycling.
- ☐ Food web characterization in Cache and Putah Creeks' watersheds has led to improved understanding of food web effects on bioaccumulation and biomagnification.
- ☐ A fish consumption study has been designed and implemented in the SRW and other Delta tributary watersheds.
- ☐ Local avian species have been monitored to assess mercury exposure and related effects.
- ☐ An MOE analysis of mercury in hair of women of child-bearing age in the SRW has been conducted.
- ☐ Other mercury-related research projects have been funded.

Outreach Activities

Early on, the DTMC developed an outline for a draft outreach strategy to engage additional stakeholder groups such as resource agency staff, land managers, community leaders, county planners, elected officials, business owners, and the general public on mercury issues (Appendix 6). Funding for an intense outreach effort was lacking; therefore, the DTMC prioritized and focused outreach efforts to attempt to increase participation in the development and authorship of this Strategic Plan. Outreach should continue to raise awareness of this Plan and its objective. The tools identified here could be useful in further educating the public on this effort, as well as in raising awareness about mercury issues in general and of work efforts being undertaken by the DTMC.

Outreach Activities Recommendation 1 (Time Frame = 0-10 years, Cost = $200K): Maintain and develop further the DTMC web site to continue to communicate appropriate and balanced information regarding fish consumption advisories in designated waterbodies. Fish consumption advisories are the only effective method for immediately reducing human exposure to mercury from fish in the watershed. The message should be balanced with a statement about the fact that fish are a high-quality food resource and information on more appropriate fishing areas.

Outreach Activities Recommendation 2 (Time Frame = 0-10 years, Cost = $20K): Work with other agencies as they develop strategic plans specific for mercury. For example, members of the DTMC should participate in the development of a strategic plan for mercury research by CALFED.

Outreach Activities Recommendation 3 (Time Frame = 0-5 years, Cost = subjective): Develop an education and outreach strategy based on the existing outline (Appendix 6) and implement it. Education and outreach are important components of the fish consumption study currently being scoped by DTMC members, including staff from the Department of Health Services, COEHHA, and the Central Valley

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[53] See http://www.oehha.ca.gov/multimedia/epic/index.html.

RWQCB. The SRW is a large region and outreach efforts may need to be phased and may work best as a joint effort among several organizations.

Outreach Activities Recommendation 4 (Time Frame = 0-5 years, Cost = $5K): Periodically update the SRWP traveling exhibit with appropriate information. The traveling exhibit was well received at the "Mercury, Mines, Rivers and You" conference in 2001 and serves as an education/outreach tool on the mercury issue and work being undertaken by the DTMC. The DTMC should continue to identify additional events to target for participation in the future.

Outreach Activities Recommendation 5 (Time Frame = 0-2 years, Cost = $20K): Develop additional outreach tools to communicate the findings of the Strategic Plan and educate the public on mercury risks. These tools may include:

- ☐ Fact sheet on mercury risks
- ☐ Fact sheet for the Strategic Plan
- ☐ Press release on mercury risks
- ☐ PowerPoint presentation on mercury risks and the Strategic Plan.

Outreach Activities Recommendation 6 (Time Frame = 1-5 years, Cost = $100K): Connect monitoring, research, and project implementation needs with funding agencies. Develop a common knowledge base for improving the funding decision process. Potential funding sources have been identified at the US Army Corps of Engineers, CALFED, and Proposition 13. The US Army Corps of Engineers' Remediation of Abandoned Mines (RAMS) Program is evaluating mine sites on public lands for possible remediation activities.

Proposition 13 funding for mine remediation stipulates (in the law) that an eligible project a) is identified in the CALFED Environmental Impact Statement / Environmental Impact Report (EIS/EIR) as a CALFED Stage 1 action, and b) constructs facilities to control drainage from abandoned mines that adversely affect water quality in the Bay-Delta. There is approximately $17 million provided in Proposition 13 to fund mine remediation projects.

In the CALFED EIR/EIS, Stage 1 actions related to mine remediation of mercury are to participate in 1) drainage control remediation of mercury mines in the Cache Creek watershed, and 2) non-specified remedial activities in the SRW. The CALFED ecological management zones only encompass the Bay-Delta watershed below the dams, so those areas may be given higher priority. Although no proposals for mine remediation were received during the 2002 solicitation period, any money not spent this year will be available in future years.

Outreach Activities Recommendation 7 (Time Frame = 0-5 years, Cost = $10K): Inform the federal legislation process. Track legislation that could limit remediation action on lands designated as wilderness or otherwise protected. Continue to stay informed about efforts to create "Good Samaritan" legislation on a national level and participate as appropriate.

Success Criteria for Outreach Activities

Success of the outreach recommendations in meeting the objective of the Strategic Plan will be judged based on the following:

- ☐ The DTMC web site is maintained and continues to post current and balanced information on fish advisories.
- ☐ A balanced, consistent message regarding risk of mercury exposure in fished waterbodies has been developed.
- ☐ A balanced and region-wide mercury risk education and outreach strategy has been developed and is being implemented.
- ☐ The SRWP traveling exhibit has been updated and used.
- ☐ Additional education and outreach tools for communicating mercury risk have been developed by the DTMC and other agencies working in the watershed and are being distributed.

- ☐ Funding sources use the Strategic Plan as part of the proposal evaluation process.
- ☐ "Good Samaritan" legislation on a national level has been promulgated.

Continuous Planning and Evaluation

The knowledge base for mercury is expanding rapidly, such that with an adaptive management strategy one can expect reasonable success in learning about mercury bioaccumulation in fish, risks posed by mercury to wildlife and people, and possible remediation solutions. Considering the multiple unknowns, continuous evaluation of research and project implementation results will be imperative. Results of those evaluations will then feed back into the Plan to provide even more appropriate recommendations to direct research and remediation activities.

Continuous Planning Recommendation 1 (Time Frame = 0-10 years, Cost = none): Continue to use the USEPA criterion as the numeric fish tissue target for the SRW and Delta until better information is developed[54]. Information regarding the consumption rate of local fish species by pregnant women and children should be collected to refine the criterion value. Outreach information should clarify that the USEPA criterion allows prediction of conditions that are not likely to be associated with any health risks but does not clearly indicate that adverse health effects will occur.

Continuous Planning Recommendation 2 (Time Frame = 0-5 years, Cost = $50K): Search for funding to maintain activity of the DTMC as a stakeholder group that also acts as a clearinghouse of information related to mercury in the Delta watershed and to continue the monitoring program within the SRWP and analyses of monitoring data. Success of efforts to reduce methylmercury exposure in humans and wildlife in this ecosystem will hinge strongly on the maintenance of strong linkages (communication and cooperation) between scientists and the involved community of resource managers, environmental planners, and other stakeholders.

Continuous Planning Recommendation 3 (Time Frame = 0-3 years, Cost = $100K): Participate in offsets program discussions to develop a format for evaluating projects. A viable mercury offsets[55] program could provide ongoing financial support for a limited number of pilot projects to show the effectiveness of selected remediation strategies. Some permitted dischargers are required to develop offsets programs to reduce mercury loads in the watershed rather than attempt to reduce further loads from their facilities, with the idea that other (uncontrolled) loads will be less expensive to reduce, thus providing a net environmental benefit.

Success Criteria for Continuous Planning and Evaluating

Success of the continuous planning and evaluating recommendations in meeting the objective of the Strategic Plan will be judged based on the following:

- ☐ The most appropriate target for reducing mercury risk in the SRW has been justified and is being used.
- ☐ The DTMC is still in existence, meeting regularly, and continuing to gather and evaluate information.
- ☐ The SRWP monitoring program is supported.
- ☐ An offset program has been developed and evaluated for success in terms of implementation of pilot projects to reduce risk of mercury in fish in the Delta watershed.

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[54] The Forum on Contaminants in Fish, co-sponsored annually by the American Fisheries Society and USEPA, should be reviewed annually for relevant information.

[55] An offset project is one done by a regulated (i.e., permitted) source of a pollutant who is required (as a permit requirement) to reduce their pollutant loads The alternative to increasing treatment of their discharges is to reduce another source for a greater overall environmental benefit. Such offsets programs are currently being developed in California, including one for mercury in the SRW.

Glossary of Acronyms

ARD – acid rock drainage

BAF – bioaccumulation factor

BASS – Bioaccumulation and Aquatic System Simulator

CALFED – California-Federal Bay-Delta Restoration Program

COEHHA – Office of Environmental Health Hazard Assessment

CTR – California Toxics Rule

DSM-II – Delta Simulation Model, version 2

DST – decision-support tool

DTMC – Delta Tributaries Mercury Council

DWR – California Department of Water Resources

EBMUD – East Bay Municipal Utility District

EIS/EIR – Environmental Impact Statement / Environmental Impact Report

EMDS – Ecosystem Management Decision Support

HSPF – Hydrologic Simulation Program-FORTRAN

ISC3 – Industrial Source Complex 3 model

MCM – Mercury Cycling Model

MOE – margin of exposure

NAWQA – National Water Quality Assessment Program

NPDES – National Pollutant Discharge Elimination System

POTW – Publicly Owned Treatment Works

RELMAP – Regional Lagrangian Model of Air Pollution

RfD – reference dose

RMA – Resource Management Associates

RWQCB – Regional Water Quality Control Board

SRW – Sacramento River watershed

SRWP – Sacramento River Watershed Program

SWRCB – State Water Resource Control Board

THg – Total mercury

TL2 – Trophic Level 2

TMDL – Total Maximum Daily Load

TSS – total suspended solids

USDA – United States Department of Agriculture

USEPA – United States Environmental Protection Agency

USFWS – United States Fish and Wildlife Service

USGS – United States Geological Survey

WARMF – Watershed Analysis Risk Management Framework

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