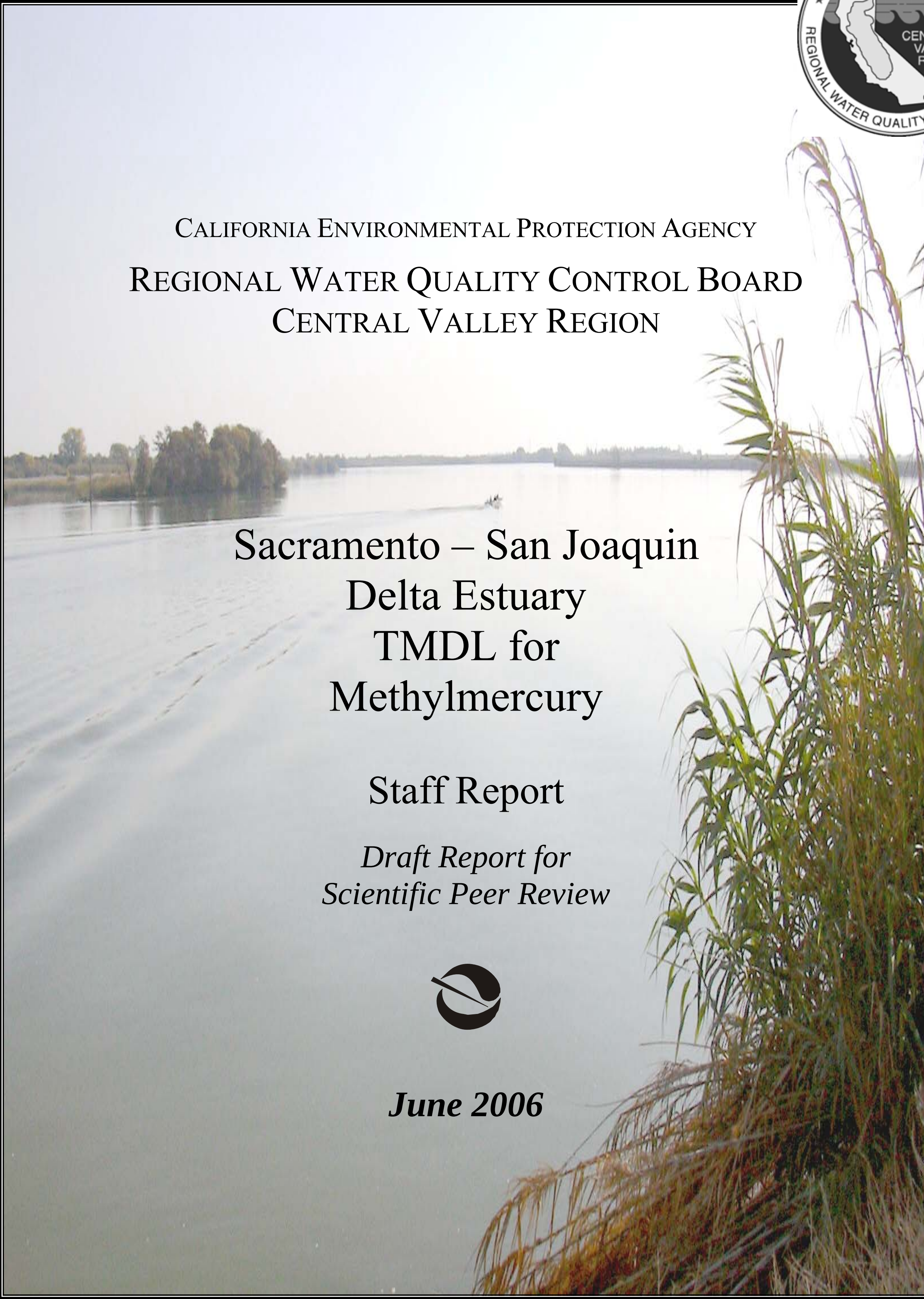

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

REGIONAL WATER QUALITY CONTROL BOARD
CENTRAL VALLEY REGION

Sacramento – San Joaquin Delta Estuary TMDL for Methylmercury

Staff Report

Draft Report for Scientific Peer Review

June 2006

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ACKNOWLEDGEMENTS

Central Valley Water Board staff gratefully acknowledges the valuable sampling, analytical and administrative support from: Greg Marquis (former staff); Dana Thomsen, Taro Murano, and Stephen Louie (Post Graduate Researchers); and Helena Kulesza and Kelly Long (Student Interns). In addition, this report greatly benefited from the ideas and data generated by: Bill Johnson and Richard Looker (San Francisco Bay RWQCB); Jay Davis, Ben Greenfield, Jon Leatherbarrow and Lester McKee (San Francisco Estuary Institute); Mark Stephenson, Wes Heim and Amy Byington (Moss Landing Marine Laboratories); David Schoellhamer (USGS); Dan Russell (USFWS); Tom Schroyer (CDFG); Darell Slotton, Shaun Ayers, and Fraser Shilling (University of California, Davis); and Stephen McCord and Khalil Abu-Saba (Larry Walker Associates).

SACRAMENTO – SAN JOAQUIN DELTA ESTUARY TMDL FOR MERCURY

EXECUTIVE SUMMARY

This draft report presents Central Valley Regional Water Quality Control Board (Central Valley Water Board) staff recommendations for establishing a Total Maximum Daily Load for methylmercury in the Sacramento-San Joaquin Delta Estuary. The report contains an analysis of the mercury impairment, a review of the primary sources, a linkage between methylmercury sources and impairments, and recommended mercury reductions to eliminate the impairment.

This TMDL report is the first component in the Central Valley Water Board's water quality attainment strategy to resolve the mercury impairment in the Delta. The second component is implementing a control program through amendments to the Water Quality Control Plan for the Sacramento River and San Joaquin River Basins (the Basin Plan), as described in the main text and Appendix A of the Proposed Basin Plan Amendment draft staff report.

Scope, Numeric Targets & Extent of Impairment

In 1990 the Central Valley Water Board identified the Delta as impaired by mercury because fish had elevated levels of mercury that posed a risk for human and wildlife consumers. As a result, the Delta methylmercury TMDL addresses all waterways within the legal Delta boundary. In addition, the San Francisco Bay Regional Water Quality Control Board (San Francisco Water Board) identified Central Valley outflows *via* the Delta as one of the principal sources of total mercury to San Francisco Bay and, in its 2004 mercury TMDL for San Francisco Bay, assigned the Central Valley a load reduction of 110 kg/yr. Therefore, the final mercury TMDL control plan for the Delta must ensure protection of human and wildlife health in the Delta and meet the San Francisco Bay load allocation to the Central Valley.

This TMDL report addresses both methyl and total mercury sources. Reductions in ambient aqueous methylmercury and methylmercury sources are required to reduce methylmercury concentrations in fish. The methylmercury linkage and source analyses divide the Delta into eight subareas based on the hydrologic characteristics and mixing of the source waters. A separate methylmercury allocation scheme is developed for each subarea because the levels of impairment and the methylmercury sources in the subareas are substantially different. Reductions in total mercury loads are needed to reduce aqueous methylmercury in the Delta, to maintain compliance with the USEPA's criterion of 50 ng/l, and to comply with the San Francisco Bay mercury control program.

The concentration of methylmercury in fish tissue is the type of numeric target selected for the Delta methylmercury TMDL. Acceptable fish tissue levels of methylmercury for the trophic level TL food groups consumed by piscivorous wildlife species were calculated using a method developed by the U.S. Fish and Wildlife Service that addresses daily intake levels, body weights and consumption rates. Numeric targets were developed to protect humans in a manner analogous to targets for wildlife using a method approved by the U.S. Environmental Protection Agency and Delta-specific information.

Three numeric targets are recommended for the protection of humans and piscivorous wildlife: 0.24 mg/kg (wet weight) in muscle tissue of large[1] trophic level four (TL4) fish such as bass and catfish; 0.08 mg/kg (wet weight) in muscle tissue of large TL3 fish such as carp and salmon; and 0.03 mg/kg (wet weight) in whole trophic level 2 and 3 fish less than 50 mm in length. The targets for large TL3 and 4 fish are protective of (a) humans eating 32 g/day (1 meal/week) of commonly consumed, large fish; and (b) all wildlife species that consume large fish. The target for small TL2 and 3 fish is protective of wildlife species that consume small fish.

It was possible to describe these recommended objectives in terms of the mercury concentration in standard 350 mm largemouth bass. A methylmercury concentration of 0.28 mg/kg in 350 mm largemouth bass is equivalent to the water quality objective of 0.24 mg/kg for large TL4 fish. A methylmercury concentration of 0.24 mg/kg in 350 mm largemouth bass is equivalent to the water quality objective of 0.08 mg/kg for TL3 fish. A methylmercury concentration of 0.42 mg/kg in 350 mm largemouth bass is equivalent to the water quality objective of 0.03 mg/kg for small fish. As a result, a methylmercury concentration of 0.24 mg/kg in 350 mm largemouth bass is referred to as the recommended implementation goal for largemouth bass.

Elevated fish methylmercury concentrations occur along the periphery of the Delta while lower body burdens occur in the central Delta. Concentrations are greater than recommended as safe by the USFWS for wildlife in all subareas except in the Central Delta subarea. The Central Delta subarea requires no reduction to meet the proposed large TL3 fish target for human protection and an 8% reduction to meet the proposed large TL4 fish target for human protection. Percent reductions in fish methylmercury levels ranging from 0% to 75% in the peripheral Delta subareas will be needed to meet the numeric targets for wildlife and human health protection.

Linkage

The Delta linkage analysis focuses on the comparison of methylmercury concentrations in water and biota. Statistically significant, positive correlations have been found between aqueous methylmercury and aquatic biota, suggesting that methylmercury levels in water may be one of the primary factors determining methylmercury concentrations in fish.

The mercury concentrations in standard 350-mm largemouth bass for each Delta subarea were regressed against the average unfiltered aqueous methylmercury concentrations. Substitution of the recommended implementation goal for largemouth bass (0.24 mg/kg) into the equation developed by this regression results in a predicted average safe aqueous methylmercury concentration of 0.066 ng/l. Incorporation of an explicit margin of safety of about 10% results in the recommended implementation goal for unfiltered ambient water of 0.06 ng/l methylmercury. This implementation goal would be applied as an annual average methylmercury concentration in ambient waters of the Delta. The recommended implementation goal is currently met in the Central Delta subarea.

[1] Large fish are defined as 150-500 mm total length or legal catch length if designated by CDFG.

Sources – Methylmercury

Average annual methylmercury inputs and exports were estimated for water years 2000 to 2003, a relatively dry period that encompasses the available information. Sources of methylmercury in Delta waters include tributary inputs from upstream watersheds and within-Delta sources such as sediment flux, municipal and industrial wastewater, agricultural drainage, and urban runoff. Losses include water exports to southern California, outflow to San Francisco Bay, removal of dredged sediments, photodegradation, uptake by biota and unknown loss term(s). Figure 1 illustrates the Delta's average daily methylmercury imports and exports. Sediment fluxes in wetland and open water habitats and tributary water bodies account for about 30 and 60%, respectively, of methylmercury inputs to the Delta. The difference between the sum of known inputs and exports is a measure of the uncertainty of the loading estimates and of the importance of other unknown processes at work in the Delta. Preliminary photodegradation study results for the Sacramento River near Rio Vista (Byington *et al.*, 2005) suggest that methylmercury loss from photodegradation may account for about 60% of the unknown loss rate illustrated in Figure 1.

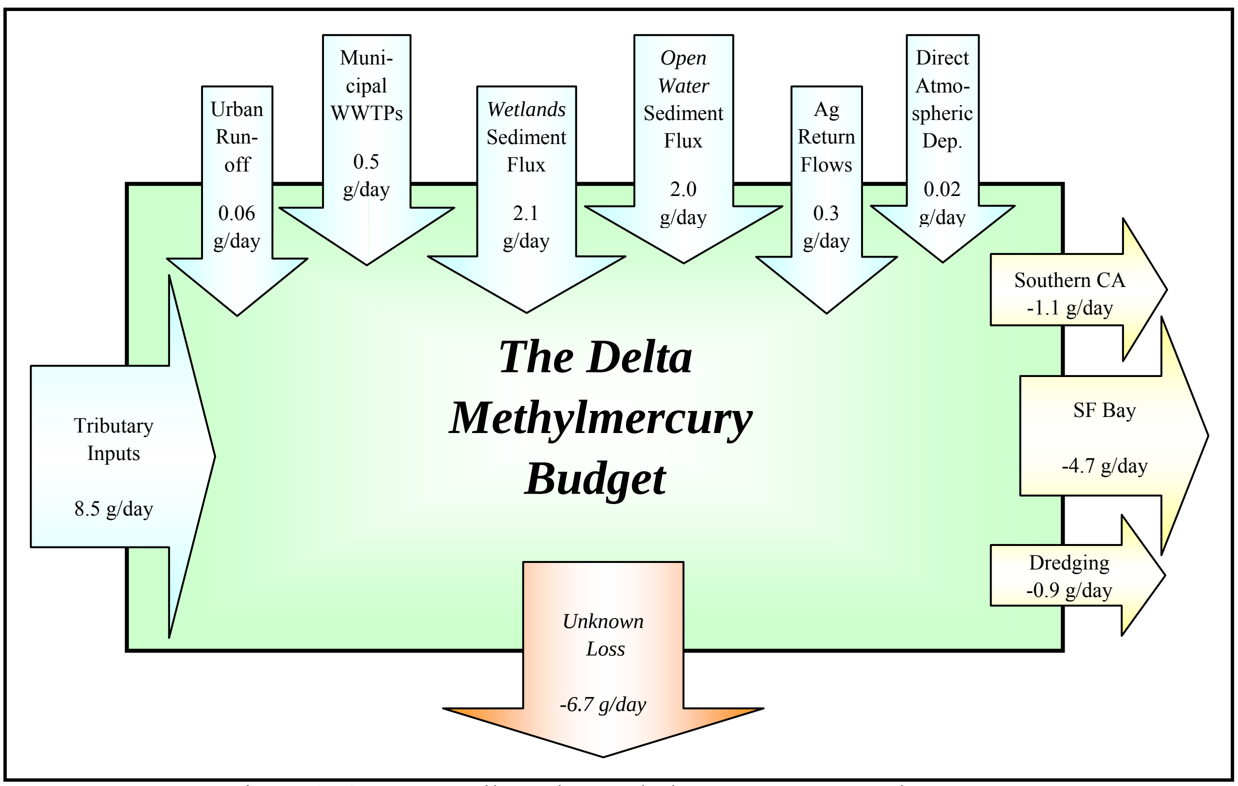

Figure 1: Average Daily Delta Methylmercury Inputs and Exports.

Sources – Total Mercury & Suspended Sediment

Sources of total mercury in the Delta include tributary inflows from upstream watersheds, atmospheric deposition, urban runoff, and municipal and industrial wastewater. More than 96% of identified total mercury loading to the Delta comes from tributary inputs; within-Delta sources are a very small component of overall loading. Losses include outflow to San Francisco Bay, water exports to southern California, removal of dredged sediments and evasion.

The Sacramento Basin (Sacramento River + Yolo Bypass) contributes approximately 80% or more of total mercury fluxing through the Delta. Of the watersheds in the Sacramento Basin, the Cache Creek and upper Sacramento River (above Colusa) watersheds contribute the most mercury. The Cache Creek, Feather River, American River and Putah Creek watersheds in the Sacramento Basin have both relatively large mercury loadings and high mercury concentrations in suspended sediment, which makes these watersheds more likely candidates for load reduction programs.

Methylmercury Allocations & Total Mercury Limits

Methylmercury allocations were made in terms of the existing assimilative capacity of the different Delta subareas. To determine reductions, the existing average aqueous methylmercury levels in the Delta subareas were compared to the proposed methylmercury goal (0.06 ng/l). The amount of reduction needed in each subarea is expressed as a percent of the ambient concentration. Percent reductions required to meet the goal ranged from 0% in the Central Delta subarea to more than 70% in the Yolo Bypass and Mokelumne River subareas.

In order to attain the desired ambient methylmercury levels in each Delta subarea, loads of methylmercury from within-Delta point and nonpoint sources and tributary inputs need to be reduced in proportion to the desired decrease in concentrations needed for ambient waters to meet the proposed goal. The percent allocations and acceptable loads and concentrations were calculated as a percent of existing loads and concentrations. The percent reductions vary by subarea because the percent reductions required for ambient water methylmercury levels in each subarea to meet the proposed methylmercury goal vary. No reductions were required for sources to the Central Delta. Percent reductions were applied to point and nonpoint source loads within other subareas, except those sources with existing average methylmercury concentrations at or below the proposed methylmercury goal of 0.06 ng/l. No individual source would be expected to reduce its discharged methylmercury concentrations to below the proposed implementation goal.

A total mercury load reduction strategy was developed to comply with the San Francisco Bay mercury control program, to maintain compliance with the USEPA's criterion of 50 ng/l, and to help reduce aqueous methylmercury in the Delta. Staff recommends total mercury load reductions from the Cache Creek, Feather River, American River and Putah Creek watersheds in the Sacramento Basin. These watersheds have both relatively large mercury loadings and high mercury concentrations in suspended sediment, which makes those watersheds likely candidates for load reduction programs. Staff also recommends that total mercury loading to the Delta not increase as a result of new or expanded projects, and that any increase in total mercury loading be mitigated or in compliance with an offset program. The TMDL for San Francisco Bay assigned the Central Valley a five-year average total mercury load reduction if 110 kg/yr. Staff considers a 110 kg reduction as a reasonable goal for the first phase of the Delta mercury control program.

The methylmercury allocations and total mercury limits described in this report reflect the preferred implementation alternative described in Chapter 4 of the Proposed Basin Plan Amendment draft staff report and are designed to address the beneficial use impairment in all subareas of the Delta and San Francisco Bay. However, as described in the Proposed Basin Plan Amendment draft staff report, a number of alternatives are possible. The Central Valley Water Board will consider a variety of mercury reduction strategies and implementation alternatives as part of the Basin Plan amendment process. All Central Valley Water Board regulatory actions will be taken in public hearings.

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ACRONYMS

ARB	California Air Resources Board
AWQC	Ambient water quality criterion
BAF	Bioaccumulation factor
Basin Plan	Central Valley Region Water Quality Control Plan for the Sacramento River and San Joaquin River Basins
bwt	Body weight
CCSB	Cache Creek Settling Basin
CDEC	California Data Exchange Center
CDFG	California Department of Fish and Game
CDHS	California Department of Health Services
CEIDARS	California emission inventory department and reporting system
cfs	Cubic feet per second
CFSII	Continuing survey of food intake by individuals
CMP	Coordinated Monitoring Program
CSS	Combined Sewer system
CTR	California Toxics Rule
CVP	Central Valley Project
CVRWQCB	Central Valley Regional Water Quality Control Board (a.k.a. Central Valley Water Board)
CWA	Federal Clean Water Act
DMC	Delta Mendota Canal
DTMC	Delta Tributaries Mercury Council
DWR	California Department of Water Resources
EC	Electrical conductivity
FCM	Food chain multipliers
GIS	Geographic Information System
HCI	Hydrologic Classification Index
Hg	Mercury
IEP	Interagency Ecological Program
IRIS	Integrated Risk Information System
LMB	Largemouth bass
LOAEC's	Lowest observed adverse effect concentrations
MCL	California/USEPA drinking water standards maximum contaminant levels
MDN	Mercury Deposition Network
mgd	Million gallons per day
MID	Modesto Irrigation District
MeHg	Monomethyl mercury (also referred to as methylmercury in this report)
MS4	Municipal Separate Storm Sewer System
NADP	National Atmospheric Deposition Program
NAS	National Academy of Sciences

NEMD	Natomas East Main Drain
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint source
NWI	National Wetland Inventory
O	Oxygen
o/oo	Parts per thousand (salinity)
OBS	Optical back scatter
OEHHA	Office of Environmental Health Hazard Assessment
RFD	Reference dose
RSC	Relative source contribution
San Francisco Water Board	San Francisco Bay Regional Water Quality Control Board
SFBADPS	San Francisco Bay Atmospheric Deposition Pilot Study
SFEI	San Francisco Estuary Institute
SRCSD	Sacramento Regional County Sanitation District
SRWP	Sacramento River Watershed Program
State Board	State Water Resources Control Board (also shown as SWRCB in reference citations)
Subwatershed	Portion of watershed that is either upstream or downstream of the most-downstream major dam
SWIM	Surface water information
SWP	State water project
SWRCB	State Water Resources Control Board
TDSL	Total diet safe level
TL	Trophic level
TLR	Trophic level ratios
TMDL	Total Maximum Daily Load
TSS	Total suspended solids
USACE	U.S. Army Corps of Engineers
USBR	U.S. Bureau of Reclamation
USEPA	U.S. Environmental Protection Agency
USFDA	U.S. Food and Drug Administration.
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
ww	Wet weight concentration (e.g., for fish tissue mercury concentrations)
WWTP	Wastewater treatment plants
X2	Location in the Estuary with 2-o/oo bottom salinity

UNITS OF MEASURE

µg	microgram
µg/g	microgram per gram
µg/l	microgram per liter
µm	micrometer
cfs	cubic feet per second
cm	centimeter
g	Gram
g/day	gram per day
g/l	gram per liter
in/yr	inches per year
kg	kilogram
l	Liter
m	Meter
mg	milligram
mg/g	milligram per gram
ml	milliliter
mm	millimeter
ng	nanograms
ng/l	nanograms per liter
o/oo	parts per thousand (salinity)
ppb	parts per billion; usually µg/kg
ppm	parts per million; usually mg/kg or µg/g
ppt	parts per trillion; usually ng/kg

1 INTRODUCTION

This draft report presents Central Valley Regional Water Quality Control Board (Central Valley Water Board) staff recommendations for establishing a Total Maximum Daily Load for methylmercury in the Sacramento-San Joaquin Delta Estuary (Figure 1.1). The report contains an analysis of the mercury impairment, a discussion of the primary sources, a linkage between sources and impairments, and recommended methyl and total mercury reductions to eliminate the impairment. The report is one component in the Central Valley Water Board's water quality attainment strategy to resolve the mercury impairment in the Delta.

The Federal Clean Water Act (CWA) requires States to identify water bodies that do not meet their designated beneficial uses and to develop programs to eliminate impairments. States refer to the control program as a Total Maximum Daily Load (TMDL) program. A TMDL is the total maximum daily load of a pollutant that a water body can assimilate and still attain beneficial uses. The Central Valley Regional Water Quality Control Board determined in 1990 that the Delta was impaired because fish had elevated levels of mercury that posed a risk for human and wildlife consumers. In addition, the San Francisco Bay Regional Water Quality Control Board (San Francisco Water Board) identified Central Valley outflows via the Delta as one of the principal sources of total mercury to San Francisco Bay and assigned the Central Valley a load reduction (Johnson & Looker, 2004). Therefore, the final mercury TMDL control plan for the Delta must ensure protection of human and wildlife health in the Delta and meet the San Francisco Bay load allocation to the Central Valley.

In order to meet State and Federal requirements, the TMDL development process must include compiling and considering available information and appropriate analyses relevant to defining the impairment, identifying sources, and assigning responsibility for actions to resolve the impairment. This report has the following sections that reflect the key elements of the Delta methylmercury TMDL development process:

- <u>Chapter 2 – Problem Statement</u>: Presents information that explains the overall regulatory framework for this TMDL, lists future milestones and describes the extent of mercury impairment in the Delta.
- <u>Chapter 3 – Controllable Processes</u>: Describes the methylation processes that are potentially controllable in the Delta. The concepts summarized in this chapter guided the development of the methylmercury TMDL for the Delta, particularly the linkage analyses (Chapter 5), methyl and total mercury source analyses (Chapters 6 & 7), and methylmercury allocation and implementation strategies described in Chapter 4 of the Proposed Basin Plan Amendment draft staff report.
- <u>Chapter 4 – Numeric Targets</u>: Proposes numeric targets for fish, which, if met, would protect beneficial uses of Delta waters.
- <u>Chapter 5 – Linkage Analysis</u>: Describes the mathematical relationship between aqueous methylmercury concentrations and the proposed numeric targets for fish mercury levels, which is used to determine an aqueous methylmercury goal that guides the allocation of methylmercury source reductions within the statutory Delta boundary and its tributary watersheds.
- <u>Chapters 6 & 7 – Source Assessment</u>: Identifies and quantifies concentrations and loads of methyl and total mercury sources.
- <u>Chapter 8 – Allocations</u>: Presents recommended methylmercury allocations and total mercury limits for Delta sources to reduce methylmercury concentrations in fish and to comply with the

USEPA's CTR and the San Francisco Bay Mercury TMDL allocation for total mercury leaving the Central Valley watershed. This chapter also describes the margin of safety afforded by the analyses' uncertainties and consideration of seasonal variations.

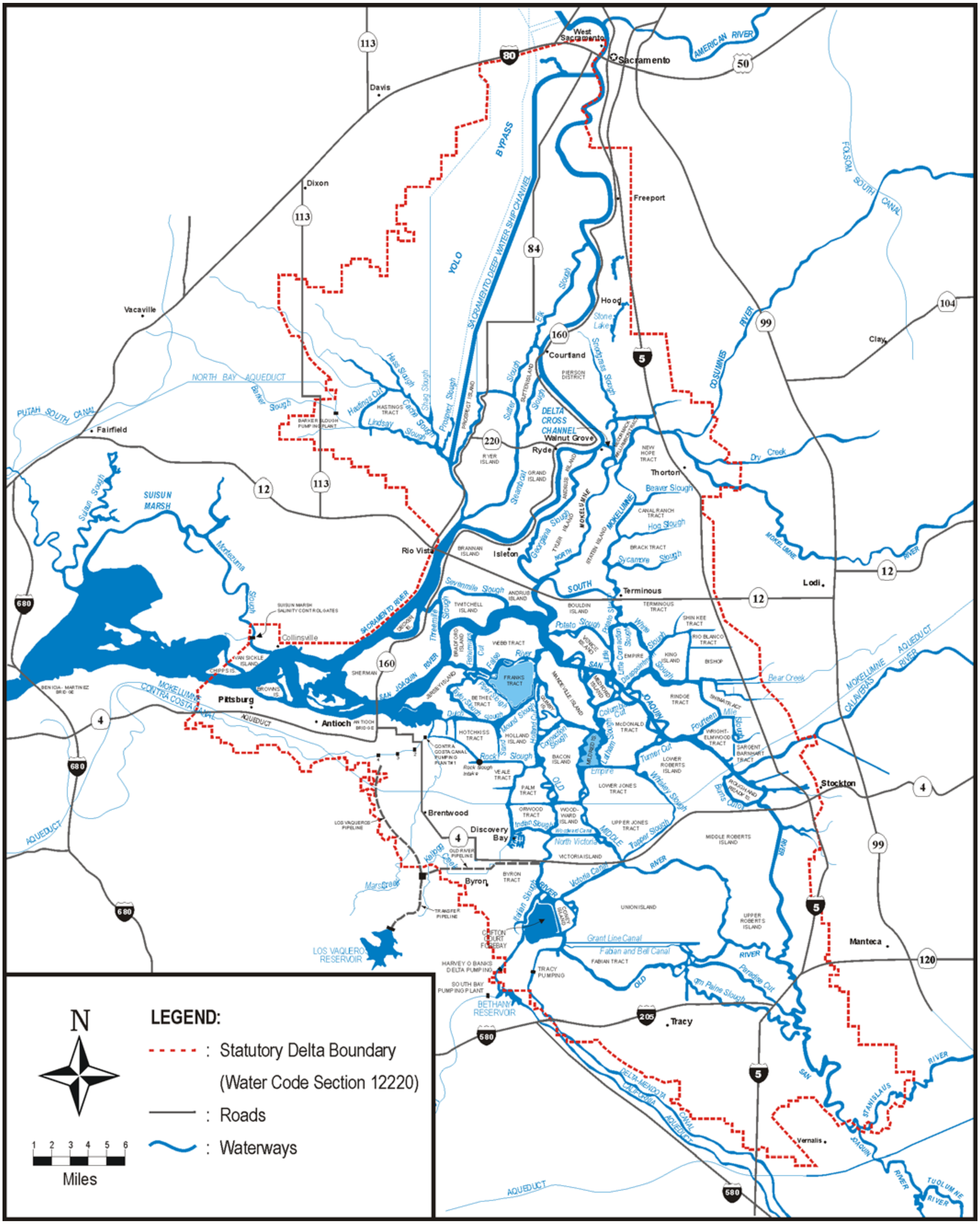

Figure 1.1: The Sacramento-San Joaquin Delta [DWR, 1995]. The dotted red line outlines the statutory boundary of the Delta. This TMDL applies to all areas in the legal Delta.

2 PROBLEM STATEMENT

The Central Valley Water Board determined that the Delta is impaired by mercury. Fish-tissue data collected since 1969 in the Delta indicate that mercury levels exceed numeric criteria established for the protection of human and wildlife health. This Problem Statement presents information in four sections:

1. Regulatory Background and TMDL Schedule
2. Delta Characteristics and TMDL Scope
3. Mercury Effects & Sources
4. Beneficial Uses, Applicable Standards & Extent of Impairment

2.1 Regulatory Background

2.1.1 Clean Water Act 303(d) Listing and Total Maximum Daily Load Development

Section 303(d) of the federal Clean Water Act requires States to:

- Identify waters not attaining water quality standards (referred to as the "303(d) list").
- Set priorities for addressing the identified pollution problems.
- Establish a "Total Maximum Daily Load" for each identified water body and pollutant to attain water quality standards.

In 1990 the State Water Resources Control Board (State Board) adopted the 303(d) List that identified Delta waterways as impaired for mercury because of the presence of a fish consumption advisory (SWRCB-DWQ, 1990). The 1998 303(d) List identified the TMDL control program for mercury in the Delta as a high priority (SWRCB-DWQ, 2003).

A TMDL represents the maximum load (usually expressed as a rate, such as kilograms per day [kg/day] or other appropriate measure) of a pollutant that a water body can receive and still meet water quality objectives. A TMDL describes the reductions needed to meet water quality objectives and allocates those reductions among the sources in the watershed. Water bodies on the 303(d) List are not expected to meet water quality objectives even if point source dischargers comply with their current discharge permit requirements. TMDLs must include the following elements: description of the problem (Chapter 2), numerical water quality target (Chapter 4), analysis of current loads (Chapters 6 and 7), and load reductions needed to eliminate impairments (Chapter 8).

2.1.2 Porter-Cologne Basin Plan Amendment Process

The State of California Porter-Cologne Water Quality Control Act (Section 13240) requires the Central Valley Water Board to develop a water quality control plan for each water body in the Central Valley that does not meet its designated beneficial uses. The Water Quality Control Plan for the Sacramento River and San Joaquin River Basins (the Basin Plan) is the legal document that describes the beneficial uses of all water bodies in these basins, water quality objectives to protect them, and, if the objectives are not being met, an implementation program to correct the impairment (CVRWQCB, 1998). The water quality management strategy for mercury in the Delta will include:

- TMDL Development: involves the technical analysis of methyl and total mercury sources, fate and transport of each, development of a proposed mercury fish tissue water quality objective and an aqueous methylmercury goal, and a description of the amount of reduction necessary to attain the proposed objective.
- Basin Planning: focuses on the development of Basin Plan amendments and a staff report for Central Valley Water Board consideration. The draft Basin Plan amendments propose site-specific water quality objectives for the Delta and an implementation plan to achieve the objectives. The Proposed Basin Plan Amendment draft staff report includes information and analyses required to comply with the California Environmental Quality Act (CEQA). The Basin Planning process satisfies State Board regulations for the implementation of CEQA.[2]
- Implementation: focuses on the establishment of a framework that ensures that appropriate practices or technologies are implemented (§13241 and §13242 of the Porter-Cologne Water Quality Act), including those elements necessary to meet federal TMDL requirements (CWA Section 303(d)).

The proposed Basin Plan amendments are legally enforceable once it has been adopted by the Regional and State Boards and approved by the Office of Administrative Law and the USEPA. Central Valley Water Board staff intends to seek public input by holding several workshops during the TMDL development and implementation planning phases. Also, the Basin Plan amendments will be adopted and approved in a public forum.

2.1.3 Timeline and Process for the Delta Mercury Management Strategy

The TMDL development, Phase I implementation planning, and preliminary Basin Planning phases of the Delta mercury management strategy should be complete in 2006 with the release of the Proposed Basin Plan Amendment draft staff report, which includes this revised TMDL report. The 2006 reports incorporate additional information from ongoing sampling and analyses and public input received on the August 2005 draft TMDL report. Additional public input will be sought during the Basin Planning phases through public workshops and formal hearings.

The Proposed Basin Plan Amendment draft staff report will be presented to the Central Valley Water Board for their consideration in 2006. Should an evaluation of implementation options developed during Phase I of the implementation program indicate that water quality objectives protective of the Delta's beneficial uses cannot be reasonably attained given control technologies and management practices developed between 2006 and 2012, staff may prepare a Use Attainability Analysis in 2013 as part of the Basin Plan amendments for the Board's consideration in 2014 (40 CFR § 131.10 (j)(2)).

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[2] The Secretary of Resources has certified the planning process for Basin Plans as a regulatory program pursuant to PRC § 21080.5 and CEQA Guidelines § 15251(g). This certification means basin planning is exempt from CEQA provisions that relate to preparing Environmental Impact Reports and Negative Declarations. The Basin Plan Staff Report satisfies the requirements of State Board Regulations for Implementation of CEQA, Exempt Regulatory Programs, which are found in the California Code of Regulations, Title 23, Division 3, Chapter 27, Article 6, beginning with Section 3775.

2.1.4 Units and Terms Used in this Report

This report uses the term "total mercury" (TotHg) to indicate the sum of all forms of mercury (Hg) in water: physical states (e.g., dissolved, colloidal or particulate bound), chemical states (e.g., elemental, mercurous ion, or mercuric ion), organic compounds (e.g., monomethylmercury), and inorganic compounds (e.g., cinnabar). Monomethylmercury is the predominant form of organic mercury present in biological systems and will be noted in this report as "methylmercury" (MeHg). Because methylmercury typically composes only a small portion of total mercury in ambient water,[3] the phrases "inorganic mercury" and "total mercury" are sometimes used synonymously.

Aqueous concentrations of methyl and total mercury are reported in units of nanograms per liter (ng/l). Aqueous methylmercury concentrations are rounded to three decimal places and total mercury concentrations are rounded to two decimal places. Concentrations of suspended sediment are analyzed as total suspended solids (TSS) and use units of milligrams per liter (mg/l) rounded to one decimal place. In Chapter 7 (Source Assessment – Total Mercury & Suspended Sediment), the concentration of total mercury in suspended sediment is calculated as the ratio of concentrations of mercury to suspended sediments (TotHg:TSS). Units for the concentration of mercury in suspended sediment are part per million (ppm; equivalent to ng/mg or mg/kg), dry weight. Mercury levels in sediment and soil are also presented as part per million, dry weight. The units for loads of methylmercury and total mercury are grams per year (g/yr) and kilograms per year (kg/yr), respectively. Sediment loads are given in terms of millions of kilograms per year (kg/yr x 10^6 or Mkg/yr). Water flow is presented in units of acre-feet per year or million acre-feet per year (M acre-ft) for annual rates, cubic feet per second (cfs) for instantaneous flow measurements, and million gallons per day (mgd) for treatment plants. All loads calculations were typically rounded to two significant figures with calculations completed prior to rounding. For this draft report, additional significant figures occasionally were included to improve the reader's ease in verifying calculations.

Concentrations of mercury in fish tissue are reported as milligrams per kilogram (mg/kg), wet weight basis, rounded to two decimal places. Mercury is typically analyzed as "total mercury" in fish because of the additional cost required for methylmercury analysis. However, mercury exists almost entirely in the methylated form in small and top trophic level[4] fish (Nichols et al., 1999; Becker, 1995; Slotton *et al.*, 2002). Therefore, even though all the fish mercury data presented in the report were generated by laboratory analyses for total mercury, the data are described as "methylmercury concentrations in fish".

Rates of consumption of fish are given as grams of fish eaten per day (g/day) or meals per week. One adult human meal is assumed to be eight uncooked ounces (227 grams). Humans and wildlife species consume fish and other aquatic organisms from various size ranges and trophic levels. Safe fish tissue

[3] For example, a comparison of average annual methylmercury and total mercury loads from tributary watersheds to the Delta (Tables 6.2 and 7.1) indicates that methylmercury loading comprises only about 2% of all total mercury loading from the tributaries.

[4] Trophic levels are numerical descriptions of an aquatic food web. The USEPA's 1997 Mercury Study Report to Congress used the following criteria to designate trophic levels based on an organism's feeding habits:

Trophic level 1:	Phytoplankton and bacteria.
Trophic level 2:	Zooplankton, benthic invertebrates and some small fish.
Trophic level 3:	Organisms that consume zooplankton, benthic invertebrates, and other TL2 organisms.
Trophic level 4:	Organisms that consume TL3 organisms.

levels are identified in Chapter 4 for different trophic level and size classifications. These classifications are termed "trophic level food groups".

For this report, methylmercury fish tissue concentrations in trophic level food groups are recommended as the TMDL water quality **targets**. The tissue targets will be proposed as options for the Central Valley Water Board to consider when adopting the Basin Plan water quality objective(s). The term **implementation goal** in this report refers to methylmercury concentrations in standard 350-mm largemouth bass and unfiltered water, which are correlated to the targets. The implementation goal for methylmercury in unfiltered water is Central Valley Water Board staff's best estimate of the annual average methylmercury concentration needed to achieve the fish tissue targets. The aqueous goal is used to determine the methylmercury load reductions necessary to meet the targets. The methylmercury water goal is not being proposed as a water quality objective.

2.2 Delta Characteristics and TMDL Scope

2.2.1 Delta Geography

The Sacramento-San Joaquin Delta, along with the San Francisco Bay, forms the largest estuary on the west coast of North America. The Delta encompasses a maze of over 1,100 miles of river channels surrounding about 738,000 acres (1,153 square miles) of dyked islands and tracts in Alameda, Contra Costa, Sacramento, San Joaquin, Solano and Yolo counties (Figure 1.1 and Figure A.1 in Appendix A). Many of the Delta waterways follow natural courses while others have been constructed to provide deep-water navigation channels, to improve water circulation, or to obtain material for levee construction (DWR, 1995). The legal boundary of the Delta is defined in California Water Code Section 12220. Appendix A illustrates the more than 100 named waterways included in this TMDL.

The Delta and its source watersheds comprise nearly 40% of the landmass of the State of California (Table 2.1 and Figure 2.1). The Sacramento, San Joaquin, Mokelumne, Cosumnes, and Calaveras rivers all flow into the Delta, carrying approximately 47% of the State's total runoff (DWR, 2005). The Sacramento River contributes an average annual water volume of 18.3 million acre-feet and the Yolo Bypass and the San Joaquin River contribute an average of 5.8 million acre-feet. Diversions in the Delta include the State Water Project (Banks Pumping Plant and the North Bay Aqueduct), Central Valley Project (Tracy Pumping Plant), and Contra Costa Water District, which withdraw average annual water volumes of about 3.7 million, 2.5 million, and 126 thousand acre-feet, respectively (DWR, 2005). During a typical water year,[5] the Delta receives runoff only from the Sacramento and San Joaquin Basins in the Central Valley (Figure 2.1). During infrequent flood events, the Tulare Basin in the southern Central Valley is connected to the San Joaquin River system.

The mean annual precipitation in the City of Stockton in the eastern Delta is approximately 14 inches, with the majority of rain falling between November and March. Temperatures at Stockton typically

[5] A "water year" (WY) is defined as the period between 1 October and 30 September of the following year; for example, WY2001 is the period between 1 October 2000 and 30 September 2001. Water year types in California are classified according to the natural water production of the major basins. See Appendix E for more information about water year classifications.

average 62 degrees Fahrenheit (^{o}F), with summer highs exceeding 90 ^{o}F and winter lows dropping below 40 ^{o}F.

The Delta had a population of 410,000 people in 1990 (DWR, 1995). As of the 2000 Census, about 462,000 people resided in the Delta Region (DWR, 2005). Rapid growth is occurring in urban areas in and surrounding the Delta, especially in Elk Grove (27% growth per year – the highest growth rate in California), Tracy (5.9% per year), Brentwood (12.3% per year), and Rio Vista (11.1% per year).

Agriculture and recreation are the two primary businesses in the Delta. The Delta also provides habitat for over five hundred species of wildlife (DWR, 1995; Herbold *et al.*, 1992). The Delta is the major source of fresh water to San Francisco Bay and supplies drinking water for over two-thirds of the State's population (over 23 million people) and irrigation water for more than seven million acres of farmland statewide (DWR, 2005). Table 2.2 lists additional features of the Delta.

Table 2.1: Spatial Perspective of the Delta and Its Source Regions

Region	Acreage	Square Miles	% of California	% of Central Valley
California	101,445,246	158,508	---	---
Central Valley	37,982,554	59,348	37%	---
Delta (statutory boundary)	737,630	1,153	1%	1.9%
Delta TMDL Source Area (Statutory Delta & all watersheds that drain directly to the Delta)	27,226,796	42,542	27%	72%
Sacramento River Watershed	17,410,314	27,204	17%	46%
San Joaquin River Watershed	9,801,103	15,314	10%	26%

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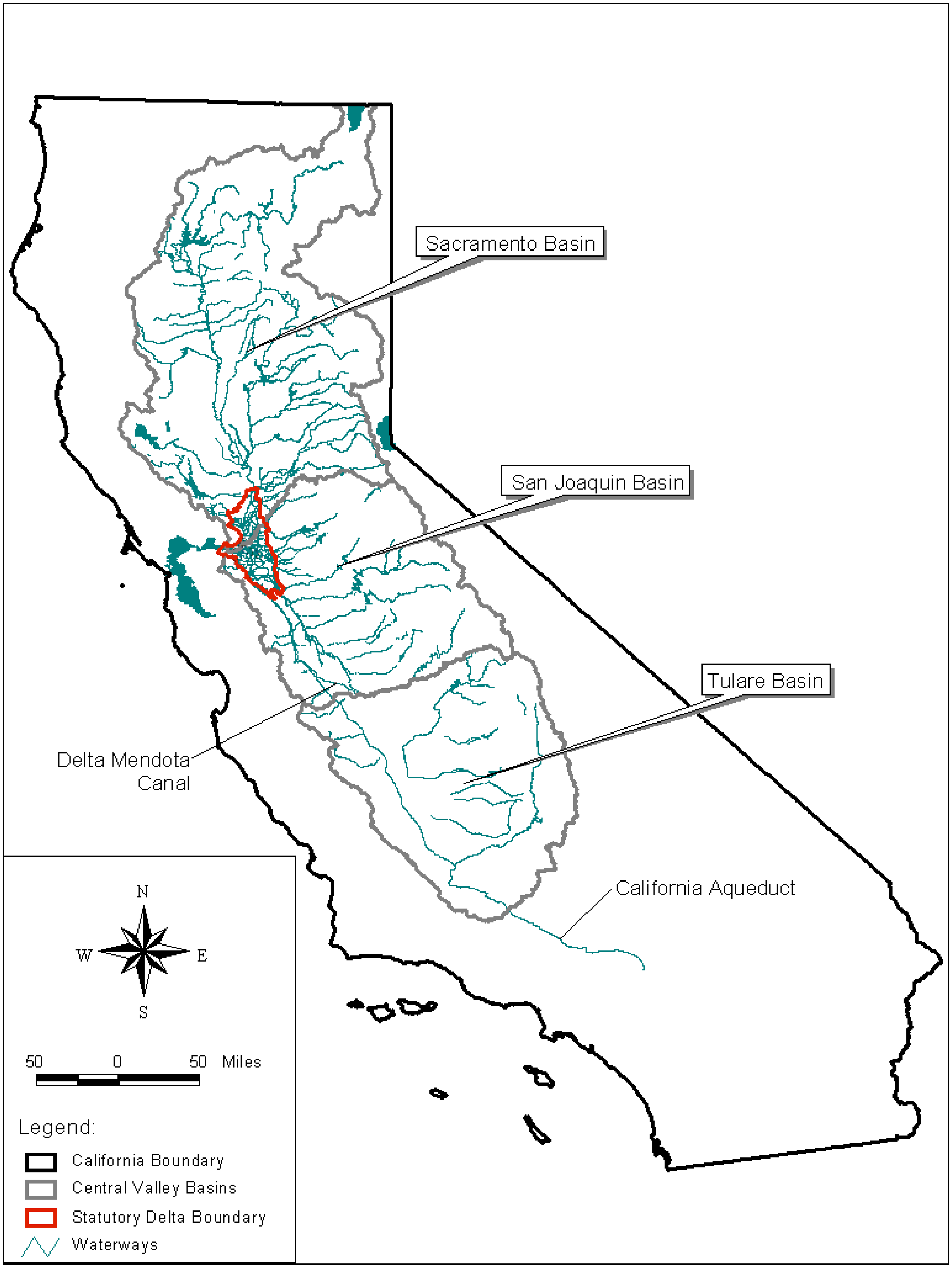

Figure 2.1: The Central Valley

Table 2.2: Key Delta Features (DWR, 1995 & 2005)

<table>
<tr><td>Population:</td><td>410,000 (1990), 462,000 (2000)</td><td rowspan="3">Area (acres):</td><td rowspan="3">Agriculture: 538,000
Cities & towns: 64,000
Water surface: 61,000
Undeveloped: 75,000
Total: 738,000</td></tr>
<tr><td>Incorporated cities entirely within the Delta:</td><td>Antioch, Brentwood, Isleton, Pittsburg, Tracy</td></tr>
<tr><td>Major cities partly within the Delta:</td><td>Sacramento, Stockton, West Sacramento</td></tr>
<tr><td># of unincorporated towns and villages:</td><td>14</td><td>Total length of all leveed channels:</td><td>1,100 miles (1987)</td></tr>
<tr><td rowspan="2">Main crops:</td><td rowspan="2">Alfalfa
asparagus
corn
fruit
grain & hay
grapes
pasture
safflower
sugar beets
tomatoes</td><td>Diversions from the Delta:</td><td>Central Valley Project
State Water Project
Contra Costa Canal
City of Vallejo
Western Delta Industry
1,800+ Agricultural diversions</td></tr>
<tr><td>Rivers flowing into the Delta:</td><td>Calaveras
Cosumnes
Sacramento
San Joaquin
Mokelumne</td></tr>
</table>

Fish and wildlife:

	# of Species	# of Federal & State Species of Concern [(a)]	# of Non-Native Species [(b)]
Birds:	230	10	3
Mammals:	45	9	7
Fish:	52	8	30
Reptiles & amphibians:	25	6	1
Flowering plants:	150	54	70
Invertebrates:	na	21	13

Major anadromous fish: American shad, salmon, steelhead trout, striped bass, sturgeon

(a) Endangered, threatened, rare, and candidate species per the federal listing effective January 31, 1992, and the State listing effective April 9, 1992.
(b) Introduced species in the Sacramento – San Joaquin Delta.

2.2.2 TMDL Scope & Delta Subareas

The scope of this mercury TMDL includes all waterways with fish within the legal Delta (Figure 1.1 and Figure A.1 in Appendix A). This TMDL focuses on fish impairment and methyl and total mercury sources identified in the Delta. Tributaries are considered to be nonpoint sources to the Delta and are evaluated at or near the locations where they cross the statutory Delta boundary. Assessment of point and nonpoint sources that contribute to tributary discharges to the Delta is ongoing and will be described in reports for future mercury TMDL programs for those watersheds and implementation activities for the Delta methylmercury TMDL.

The methylmercury source analysis and linkage analysis for the Delta TMDL divide the Delta into eight regions based on the hydrologic characteristics and mixing of the source waters (Figure 2.2). A hydrology-based methylmercury TMDL is proposed in this report as it more accurately reflects the concentrations and sources of methylmercury and the extent of fish impairment. As described in Chapter 8 (Allocations), essentially a separate methylmercury allocation scheme is developed for each

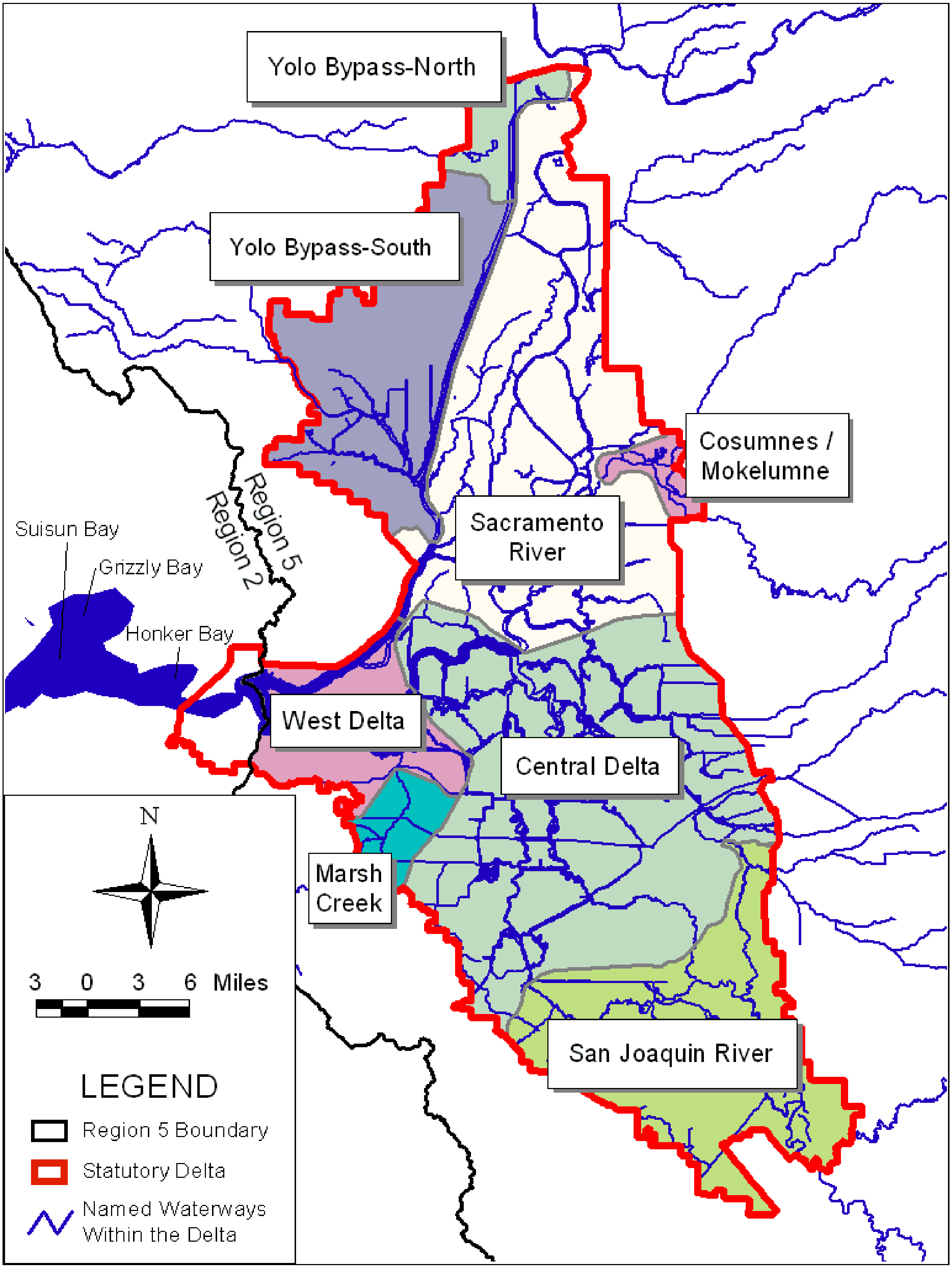

Figure 2.2: Hydrology-Based Delineation of Subareas within the Legal Delta.

subarea because the methylmercury sources and level of fish impairment in each subarea are different. The following paragraphs describe the delineation of the hydrologic subareas.

Sacramento River: This subarea is dominated by Sacramento River flows. It is bound to the east by the legal Delta boundary and to the west by the eastern levee of the Sacramento Deep Water Ship Channel. Sacramento River flows influence the Upper and Lower Mokelumne River in the Delta because of diversions by the Delta Cross Channel near Walnut Grove (Figure A.1 in Appendix A). The Delta Cross Channel controls diversions of fresh water from the Sacramento River to Snodgrass Slough and the Mokelumne River to combat salt-water intrusion in the Delta, to dilute local pollution, and to more efficiently supply the federal Central Valley Project and State Water Project pumps in the southern Delta.

Although drawn as a defined line, the Sacramento River subarea's boundary with the South Yolo Bypass, Central Delta, and West Delta subareas is defined by a gradient in water quality characteristics that varies depending on the tidal cycle, magnitude of wet weather flows, diversions by within-Delta control structures, and releases from reservoirs in the upstream watersheds. The boundary shown in Figure 2.2 is based on available information and may shift as results from ongoing and future studies become available.

Yolo Bypass - North & South: The Yolo Bypass is a floodplain on the west side of the lower Sacramento River (Section E.2.2 and Figure E.1 in Appendix E). The Fremont and Sacramento Weirs route floodwaters to the Yolo Bypass from the Sacramento and Feather Rivers and their associated tributary watersheds. Cache and Putah Creeks, Willow Slough, and the Knights Landing Ridge Cut from the Colusa Basin all drain directly to the Yolo Bypass. The legal Delta encompasses only the southern two thirds of the Yolo Bypass. The "Yolo Bypass – North" subarea is defined by the legal Delta boundary to the north and Lisbon Weir to the south. The "Yolo Bypass – South" subarea is defined by Lisbon Weir to the north and the southern end of Cache Slough to the south. Lisbon Weir (Figure E.1) limits the range of tidal fluctuation upstream in the Yolo Bypass.

Cosumnes/Mokelumne Rivers: This subarea includes the lower Cosumnes and Mokelumne Rivers and is defined by the legal Delta boundary to the east and the Delta Cross Channel confluence with the Mokelumne to the west.

San Joaquin River: The subarea is defined by the legal Delta boundary to the east and south, and Grantline Canal and the beginning of the Stockton Deep Water Channel to the north. At present, the San Joaquin River is almost entirely diverted out of the Delta by way of Old River and Grantline Canal for export south of the Delta via the State and federal pumping facilities near Tracy.

Marsh Creek: This subarea is defined by the portion of the Marsh Creek watershed within the legal Delta boundary that is upstream of tidal effects.

West Delta: The West Delta subarea encompasses the confluence of the Sacramento and San Joaquin Rivers, which transport water from the Central Valley to the San Francisco Bay. The western border of the West Delta subarea is defined by the jurisdictional boundary between the Central Valley Regional Water Quality Control Board (Region 5) and the San Francisco Water Board (a.k.a. Region 2) (Figure 2.2). Water quality characteristics are determined by the tidal cycle, magnitude of wet weather flows, controlled flow diversions by within-Delta structures, and releases from reservoirs in the upstream watersheds.

Central Delta: The Central Delta includes a myriad of natural and constructed channels that transport water from the upper watersheds to San Francisco Bay to the west and the State and federal pumps to the southwest. The Central Delta tends to be most influenced by waters from the Sacramento River.

2.3 Mercury Effects & Sources

2.3.1 Mercury Chemistry and Accumulation in Biota

Mercury (Hg) can exist in various forms in the environment. Physically, mercury can exist in water in a dissolved, colloidal or particulate bound state. Chemically, mercury can exist in three oxidation states: elemental (Hg^{o}), mercurous ion (monovalent, Hg^{+}), or mercuric ion (divalent, Hg^{+2}). Ionic mercury can react with other chemicals to form both organic and inorganic compounds, such as cinnabar (HgS), and can be converted by sulfate reducing bacteria to more toxic organic compounds, such as monomethylmercury (CH_3Hg) or dimethylmercury ($(CH_3)_2Hg$). Important factors controlling the conversion rate of inorganic to organic mercury include temperature, percent organic matter, redox potential, salinity, pH, and mercury concentration. Monomethylmercury is the predominant form of organic mercury present in biological systems and will be noted in this report as methylmercury or "MeHg". Because dimethylmercury is an unstable compound that dissociates to monomethylmercury at neutral or acid pH, it is not a concern in freshwater systems (USEPA, 1997a).

Both inorganic and organic mercury can be taken up by aquatic organisms from water, sediments and food. Low trophic level species such as phytoplankton obtain all their mercury directly from the water. *Bioconcentration* describes the net accumulation of mercury directly from water. The *bioconcentration factor* is the ratio of mercury concentration in an organism to mercury concentration in water. Mercury may also accumulate in aquatic organisms from consumption of mercury-contaminated prey (USEPA, 1997b). Mercury *bioaccumulates* in organisms when rates of uptake are greater than rates of elimination.

Repeated consumption and accumulation of mercury from contaminated food sources results in tissue concentrations of mercury that are higher in each successive level of the food chain. This process is termed *biomagnification*. Methylmercury accumulates within organisms more than inorganic mercury because inorganic mercury is less well absorbed and/or more readily eliminated than methylmercury. The proportion of mercury that exists as the methylated form generally increases with the level of the food chain, typically greater than 90% in top trophic level fish (Nichols *et al.*, 1999; Becker, 1995).

Consumption of contaminated, high trophic level fish is the primary route of methylmercury exposure. For example, the aquatic food web provides more than 95% of humans' intake of methylmercury (USEPA, 1997a). Wildlife species of potential concern that consume fish and other aquatic organisms from the Delta include piscivorous fish, herons, egrets, mergansers, grebes, bald eagle, kingfisher, peregrine falcon, osprey, mink, raccoon and river otter.

2.3.2 Toxicity of Mercury

Mercury is a potent neurotoxicant. Methylmercury is the most toxic form of this metal. Methylmercury exposure causes multiple effects, including tingling or loss of tactile sensation, loss of muscle control, blindness, paralysis, birth defects and death. Adverse neurological effects in children appear at dose levels five to ten times lower than associated with toxicity in adults (NRC, 2000). Children may be exposed to methylmercury during fetal development, by eating fish, or through both modes. Effects of methylmercury are dose dependent.

Wildlife species may also experience neurological, reproductive or other detrimental effects from mercury exposure. Behavioral effects such as impaired learning, reduced social behavior and impaired physical abilities have been observed in mice, otter, mink and macaques exposed to methylmercury (Wolfe *et al.*, 1998). Reproductive impairment following mercury exposure has been observed in multiple species, including common loons and western grebe (Wolfe *et al.*, 1998), walleye (Whitney, 1991 in Huber, 1997), mink (Dansereau *et al.*, 1999) and fish (Huber, 1997; Wiener and Spry, 1996).

2.3.3 Mercury Sources & Historic Mining Activities

Identified sources of methyl and total mercury in the Delta and in tributary watersheds include geothermal springs, sediment flux from wetlands and open water habitat, municipal and industrial dischargers, agricultural drainage, urban runoff, atmospheric deposition, and erosion of naturally mercury-enriched soils and excavated overburden and tailings from historic mining operations. Although none are present within the legal Delta, historic mercury and gold mining sites – along with their associated contaminated waterways – may contribute a substantial portion of the mercury in the tributary discharges to the Delta. Chapters 6 and 7 provide a detailed assessment of the within-Delta sources of mercury.

As noted in source analyses in Chapters 6 and 7, tributary inputs to the Delta are the largest sources of methyl and total mercury. These tributaries drain many of the major mercury mining districts in the Coast Range and the placer gold mining fields in the Sierra Nevada Mountains. The Coast Range is a region naturally enriched in mercury. Active geothermal vents and hot springs deposit mercury, sulfur, and other minerals at or near the earth's surface. Most of the mercury deposits in California occur within a portion of the Coast Range geomorphic province extending from Clear Lake in Lake County in the north to Santa Barbara County in the south. Approximately 90% of the mercury (roughly 104 million kilograms) used in the United States between 1846 and 1980 was mined in the Coast Range of California (Churchill, 1999). Much of the mining and extraction occurred prior to 1890 when mercury processing was crude and inefficient. The ore was processed at the mine sites, with about 35 million kilograms of mercury lost at the mine sites. As a result, high levels of mercury are present in sediment and fish tissue in Coast Range water bodies. Fish advisories have been posted for Clear Lake, Cache Creek, Lake Berryessa and Black Butte Reservoir (Stratton *et al.*, 1987; Brodberg & Klasing, 2003; Gassel *et al.*, 2005). Mercury mine waste enters the Delta from mine-impacted Coast Range creeks such as Cache, Putah and Marsh Creeks.

Approximately 10 million kilograms of Coast Range mercury were transported across the valley and used as an amalgam in placer and lode gold mining in the Sierra Nevada's between 1850 and 1890 (Churchill, 1999). Approximately six million kilograms of mercury were lost in Sierra Nevada rivers and streams during gold mining operations. Principal gold mining areas were in the Yuba River and Bear River (tributaries to the Sacramento River via the Feather River), the Cosumnes River (a tributary to the Mokelumne River), and the Stanislaus, Tuolumne and Merced Rivers (tributaries to the San Joaquin

River). Elevated mercury concentrations are present in fish from all these Sierra Nevada waterways. Floured[6] elemental mercury enters the Delta from the Sacramento, Mokelumne and San Joaquin Rivers.

Evaluation of legacy mine sites, associated contaminated waterway reaches, and other methyl and total mercury sources that contribute to tributary inputs to the Delta is ongoing. More detailed source analyses for the tributary watersheds will be conducted by future mercury TMDL programs for those watersheds and by proposed implementation actions for the Delta mercury control program (see Chapter 4 in the Proposed Basin Plan Amendment draft staff report).

2.4 Beneficial Uses, Applicable Standards & Extent of Impairment

2.4.1 Sacramento-San Joaquin Delta Estuary Beneficial Uses

The Federal Clean Water Act and the State Water Code (Porter-Cologne Water Quality Act) require the State to identify and protect the beneficial uses of its waters. Table 2.3 lists the existing beneficial uses of the Delta. Contact recreation (REC-1) and wildlife habitat (WILD) are impaired because of elevated mercury concentrations in fish throughout the Delta. Municipal and domestic supply (MUN) is impaired because of elevated mercury concentrations in water in the Yolo Bypass. The Basin Plan does not include a commercial and sport fishing (COMM) designation for the Delta, which includes uses of water for commercial or recreational collection of fish, shellfish, or other organisms intended for human consumption or bait purposes. However, as described in Appendix C, commercial and sport fishing take place in the Delta. Some sport and commercial species (e.g., striped bass and largemouth bass) are impaired by mercury, while others (e.g., salmon and clams) are not. The Proposed Basin Plan Amendment draft staff report (Chapter 2) considers adoption of a COMM beneficial use for the Delta.

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[6] Flouring is the division of mercury into extremely small globules, which gives it a white, flour-like appearance. If the floured mercury has surface impurities such as oil, grease, clay or iron and base metal sulfides, it will not coalesce into larger drops or form an amalgam with gold (Beard, 1987). Mercury was used for gold recovery throughout the Sierra Nevada. Floured mercury was formed by the pounding of boulders and gravels over liquid mercury in hydraulic mining-related sluice boxes (Hunerlach *et al.*, 1999), as well by intense grinding in the hardrock milling systems, and was transported downstream with tailings.

Table 2.3: Existing Beneficial Uses of the Delta (a)

Beneficial Use	Status
Municipal and domestic supply (MUN)	Existing (b)
Agriculture – irrigation and stock watering (AGR)	Existing
Industry – process (PROC) and service supply (IND)	Existing
Contact recreation (REC-1) (c)	Existing (b)
Non-contact recreation (REC-2) (c)	Existing
Freshwater habitat (warm and cold water species)	Existing
Spawning, reproduction and/or early development of fish (SPWN) (warm water species)	Existing
Wildlife habitat (WILD)	Existing (b)
Migration of aquatic organisms (MIGR) (warm and cold water species)	Existing
Navigation (NAV)	Existing

(a) This table lists the beneficial uses designated for the Delta in Table II-1 of the Water Quality Control Plan for the Sacramento River and San Joaquin River Basins (CVRWQCB, 1998).
(b) These are beneficial uses impaired by mercury in the Delta.
(c) REC-1 includes recreational activities involving body contact with water, where ingestion of water is reasonably possible. These uses include, but are not limited to, swimming, wading, water-skiing and fishing. REC-2 includes recreational activities involving proximity to water, but where there is generally no body contact with water, nor any likelihood of ingestion of water. These uses include, but are not limited to, picnicking, sunbathing, hiking, beachcombing, camping, boating, hunting and sightseeing.

2.4.2 Applicable Standards & Extent of Impairment

The narrative water quality objective for toxicity in the Basin Plan states, "All waters shall be maintained free of toxic substances in concentrations that produce detrimental physiological responses in human, plant, animal, or aquatic life." The narrative toxicity objective further says that "The Regional Water Board will also consider … numerical criteria and guidelines for toxic substances developed by the State Water Board, the California Office of Environmental Health Hazard Assessment, the California Department of Health Services, the U.S. Food and Drug Administration, the National Academy of Sciences, the USEPA, and other appropriate organizations to evaluate compliance with this objective" (CVRWQCB, 1998). Four potential criteria were evaluated to determine whether the Delta was in compliance with the narrative objective. They are the USEPA and USFWS fish tissue criteria for protection of human and wildlife, the USEPA aqueous methylmercury criterion for drinking water, the United Nations aqueous total mercury guidance level to protect livestock, and the California Toxic Rule (CTR) aqueous total mercury criterion for protection of human and wildlife health. Each is reviewed below and a determination made as to whether the recommended criteria or objective is met in the Delta or not.

2.4.2.1 Fish Tissue Criteria

In 1971 a human health advisory was issued for the Sacramento-San Joaquin Delta advising pregnant women and children not to consume striped bass. In 1994 an interim advisory was issued by the California Office of Environmental Health Hazard Assessment for San Francisco Bay and Delta recommending no consumption of large striped bass and shark because of elevated concentrations of mercury and polychlorinated biphenyls (OEHHA, 1994). Additional monitoring indicates that several more species, including largemouth bass and white catfish (two commonly-caught local sport fish), also have elevated concentrations of mercury in their tissue (Davis *et al.*, 2003; Slotton *et al.*, 2003; LWA, 2003; SWRCB-DWQ, 2002).

The Delta was listed for mercury because of the 1971 and 1994 fish advisories and because some fish tissue concentrations exceeded the National Academy of Sciences (NAS) guidelines for protection of wildlife health. The NAS wildlife guideline is 0.5-mg/kg-mercury in whole, freshwater fish (NAS, 1973). The USEPA has since published a recommended criterion for the protection of human health of 0.3 mg/kg mercury in fish tissue (USEPA, 2001). Similarly, the USFWS has provided guidance on safe methylmercury ingestion rates for sensitive wildlife species (USFWS, 2002, 2003 & 2004). The Delta TMDL cites the USEPA and USFWS recommended criteria for protection of human and wildlife health, as these are the more protective.

Significant regional variations in fish tissue mercury concentrations are observed in the Delta. Elevated concentrations occur along the periphery of the Delta while lower body burdens are measured in the central Delta. A summary of fish tissue methylmercury concentrations by Delta subarea is provided in Chapter 4 (Tables 4.7 and 4.10) and Appendix C. Concentrations are greater than recommended as safe by the USEPA and USFWS at all locations except in the central Delta. Percent reductions in fish methylmercury levels ranging from 0% to 75% in the peripheral Delta subareas will be needed to meet the numeric targets for wildlife and human health protection.

2.4.2.2 Aqueous Criteria & Guidance

The USEPA recommends a safe level of 70 ng/l methylmercury in drinking water to protect humans (USEPA, 1987). This level was released through USEPA's Integrated Risk Information System (IRIS) and was based on USEPA's recommended methylmercury reference dose for lifetime exposure. Methylmercury concentrations in the Delta typically range from 0.02 to 0.3 ng/l (Section 6.2.1). The maximum observed concentration in the Delta between March 2000 and April 2004 was 0.70 ng/l in Prospect Slough in March 2000 (Appendix M). The USEPA IRIS drinking water criterion is not expected to be exceeded in the Delta.

The United Nations recommends a guidance level of 10,000 ng/l unfiltered total mercury to protect livestock drinking water (Ayers and Westcot, 1985). Unfiltered mercury concentrations in the Delta typically range from 0.26 to 100 ng/l (Table 7.4 in Chapter 7). The maximum concentration ever observed in the Delta was 696 ng/l at Prospect Slough on January 10, 1995. The United Nations recommended livestock guidance level is not expected to be exceeded in the Delta.

The USEPA promulgated the CTR in April 2000 (USEPA, 2000). The CTR mercury objective is 0.05 µg/L (50 ng/l) total recoverable mercury for freshwater sources of drinking water. The CTR criterion was developed to protect humans from exposure to mercury in drinking water and in contaminated fish. It is enforceable for all waters with a municipal and domestic water supply or aquatic beneficial use designation. This includes all subareas of the Delta. The CTR does not specify duration or frequency. The Central Valley Water Board has previously employed a 30-day-averaging period with an allowable exceedance frequency of once every three years.[7] The USFWS and U.S. National Marine Fisheries Service are concerned that the mercury objective in the CTR may not protect threatened and

[7] Personal communication from P. Woods (USEPA Region 9) to J. Marshack (CVRWQCB), 4 December 2001.

endangered species and requested that the USEPA reevaluate the criterion. The USEPA has not released a reevaluation. Therefore, the CTR objective of 50 ng/l is applicable to the Delta.

An evaluation of unfiltered total mercury concentrations in Delta water demonstrates that the CTR is not exceeded anywhere in the Delta except downstream of the Cache Creek Settling Basin in the Yolo Bypass and possibly in Putah Creek, Prospect Slough and Marsh Creek (Section 7.5). The exceedances downstream of Cache Creek may be addressed by the Cache Creek mercury control program (CVRWQB, 2005) adopted in October 2005 and proposed upgrades of the Cache Creek Settling Basin described in Chapter 4 of the Proposed Basin Plan Amendment draft staff report. Prospect Slough is downstream of Cache Creek and potential exceedances of the CTR could be corrected with decreases in mercury loads from Cache Creek and its Settling Basin. Putah and Marsh Creeks are both on the 303(d) list because of elevated mercury concentrations. Exceedance of the CTR downstream of these water bodies will be addressed by load reductions to be determined by their TMDLs. Chapters 7 and 8 will provide additional evaluations of total mercury loads from these watersheds and potential reduction strategies.

2.4.2.3 San Francisco Bay Mercury TMDL's Allocation for Total Mercury in Central Valley Outflows

As a component of the mercury control program for the San Francisco Bay, San Francisco Water Board staff developed a target for San Francisco Bay sediment mercury concentration (particle-bound mercury mass divided by sediment mass) of 0.2 mg/kg and assigned the Central Valley a five-year average total mercury load allocation of 330 kg/yr at Mallard Island or a decrease of 110 kg/yr in mercury sources to the Delta. Compliance with the allocation can be assessed by one of two methods:

> "First, attainment may be demonstrated by documentation provided by the Central Valley Water Board that shows a net 110 kg/yr decrease in total mercury entering the Delta from within the Central Valley region. Alternatively, attainment of the load allocation may be demonstrated by multiplying the flow-weighted suspended sediment mercury concentration by the sediment load measured at the RMP Mallard Island monitoring station. If sediment load estimates are unavailable, the load shall be assumed to be 1,600 million kg of sediment per year. The mercury load fluxing past Mallard Island will be less than or equal to 330 kg/yr after attainment of the allocation." (Johnson & Looker, 2004)

Central Valley Water Board staff will recommend to the Central Valley Water Board that the 110 kg total mercury reduction be met by reductions in total mercury entering the Delta from within the Central Valley. Reduction efforts are recommended for the Cache Creek, Feather River, American River and Putah Creek watersheds because they export the largest volume of highly contaminated sediment (see Chapter 8 in this TMDL report and Chapter 4 in the Proposed Basin Plan Amendment draft staff report). Load calculation methods and strategies for meeting reduction in total mercury loading to San Francisco Bay are discussed in more detail in Chapters 7 and 8 of this report.

Key Points

- The Federal Clean Water Act (CWA) requires States to identify water bodies that do not meet their designated beneficial uses and to develop programs to eliminate impairments. States refer to the control program as a Total Maximum Daily Load (TMDL) program. A TMDL is the total maximum daily load of a pollutant that a water body can assimilate and still attain beneficial uses.
- The State of California Porter-Cologne Water Quality Control Act requires the Central Valley Water Board to develop a water quality control plan for each water body in the Central Valley that does not meet its designated beneficial uses. The Water Quality Control Plan for the Sacramento River and San Joaquin River Basins (the Basin Plan) is the legal document that describes the beneficial uses of all water bodies in these basins, adopted water quality objectives to protect them, and, if the objectives are not being met, an implementation program to correct the impairment.
- The TMDL development, implementation planning, and preliminary Basin Planning phases of the Delta mercury management strategy should be complete in 2006 with the release of the Proposed Basin Plan Amendment draft staff report, which includes this revised TMDL report. The final staff report will be presented to the Central Valley Water Board for their consideration in late 2006.
- In 1990 the Central Valley Water Board identified the Delta as impaired by mercury because fish had elevated levels of mercury that posed a risk for human and wildlife consumers. In addition, the San Francisco Bay mercury control program identified Central Valley outflows via the Delta as one of the principal sources of total mercury to San Francisco Bay and assigned the Central Valley a load reduction of 110 kg/yr. Therefore, the final mercury TMDL control plan for the Delta must ensure protection of human and wildlife health in the Delta and meet the San Francisco Bay load allocation to the Central Valley.
- The scope of the Delta methylmercury TMDL includes all waterways within the legal Delta boundary. This TMDL report addresses both methyl and total mercury. Reductions in aqueous methylmercury are required to reduce methylmercury concentrations in fish. Reductions in total mercury loads are needed to maintain compliance with the USEPA's criterion of 50 ng/l; to prevent increases in total mercury discharges from causing increases in aqueous and fish methylmercury in the Delta, thereby worsening the impairment; and to meet the San Francisco Bay TMDL allocation to the Central Valley.
- Elevated fish mercury concentrations occur along the periphery of the Delta while lower body burdens are measured in the central Delta. Concentrations are greater than recommended as safe by the USEPA and USFWS at all locations except in the central Delta. Percent reductions in fish methylmercury levels ranging from 0% to 73% in the peripheral Delta subareas will be needed to meet the numeric targets for wildlife and human health protection.

3 POTENTIALLY CONTROLLABLE METHYLATION PROCESSES IN THE DELTA

The problem with mercury in the Delta's aquatic ecosystems can be defined as biotic exposure to methylmercury (Wiener *et al.*, 2003a). Therefore, decreasing biotic exposure to methylmercury is the ultimate goal of the Delta methylmercury TMDL and implementation program. Several published papers provide comprehensive reviews of the current knowledge of the methylmercury cycle (e.g., Wiener *et al.*, 2003a & 2003b; Tetra Tech, Inc. 2005; LWA, 2002). This chapter focuses on the processes that are potentially controllable in the Delta. The concepts summarized in this chapter guided the development of the methylmercury TMDL for the Delta, particularly the linkage analyses (Chapter 5), methyl and total mercury source analyses (Chapters 6 & 7), and recommended methylmercury allocations and total mercury limits (Chapters 8). Data gaps and uncertainties associated with each factor are identified in this chapter and then addressed further by recommendations for source characterization and control studies in Chapter 4 of the Proposed Basin Plan Amendment draft staff report.

Methylmercury concentrations in aquatic ecosystems are the result of two competing processes: methylation and demethylation. Neither is well understood. Methylation is the addition of a methyl group to an inorganic mercury molecule (Hg^{+2}). Sulfate reducing bacteria are the primary agents responsible for the methylation of mercury in aquatic ecosystems (Compeau and Bartha, 1985; Gilmour *et al.* 1992). Small amounts of methylmercury also may be produced abiotically in sediment (Falter and Wilken, 1998). Maximum methylmercury production occurs at the oxic-anoxic boundary in sediment, usually several centimeters below the surface. Although less common, methylmercury also may be formed in anaerobic water (Regnell *et al.*, 1996 & 2001). In this case, mercury-methylating microbes move from the sediment to the overlying water and the resulting methylmercury becomes available to the biotic community when aerobic and anaerobic waters mix.

Demethylation is both a biotic and abiotic process. Both sulfate reducing and methanogen-type bacteria have been reported to demethylate mercury in sediment with maximum demethylation co-occurring in the same zone where maximum methylmercury production is located (Marvin-DiPasquale *et al.*, 2000). Photodegradation of methylmercury in the water column also has been observed (Sellers *et al.*, 1996; Byington *et al.*, 2005). While not well studied, the rate of both biotic and abiotic demethylation appear quantitatively important in controlling net methylmercury concentrations in aquatic ecosystems (Sellers & Kelly, 2001; Marvin-DiPasquale *et al.*, 2000).

Factors controlling sediment methylmercury production have been the subject of intense scientific research (for reviews see Wiener *et al.*, 2003b and Benoit *et al.*, 2002). Sediment factors and landscape events important in net methylmercury production include:

- Sulfate and pH concentration of the overlying water (Gilmour *et al.*, 1998; Miskimmin *et al.*, 1992; Krabbenhoft *et al.*, 1999);
- Percent organic content of the sediment (Krabbenhoft *et al.*, 1999; Miskimmin *et al.*, 1992; Hurley *et al.*, 1998; Heim *et al.*, 2003; Slotton *et al.*, 2003);
- Creation of new water impoundments (Verdon *et al.*, 1991; Bodaly *et al.*, 1997);
- Amount and kind of inorganic mercury present in the sediment (Krabbenhoft *et al.*, 1999; Bloom, 2003); and

- Amount of permanent or seasonally flooded wetland in a watershed (Krabbenhoft *et al*., 1999; Brumbaugh *et al*., 2001; St Louis *et al*., 1994 & 1996; Hurley *et al*., 1995).

The organic content of the sediment and the pH of the overlying water are not discussed further as neither appears controllable in the Delta.

3.1 Sulfate

Sulfate is used by sulfate reducing bacteria as the terminal electron acceptor in the oxidation of organic material. Sulfate additions have been observed to both stimulate (Gilmour *et al.*, 1992; King *et al.*, 2002) and inhibit (Benoit *et al.*, 1999; Gilmour *et al.*, 1998) methylmercury production. Addition of sulfate is predicted to stimulate methylmercury production when it is limiting. In contrast, sulfate amendments may inhibit production when excess sulfide is present. Sulfide is the primary byproduct in the reduction of sulfate and increasing sulfide concentrations may cause inhibition by either decreasing the amount of neutrally charged dissolved mercury-sulfide complexes[8] (Benoit *et al.*, 1999 & 2001, but see Kelley *et al.*, 2003, for conflicting results) or by precipitating insoluble mercuric sulfide (Compeau & Bartha, 1985).

Two factors influencing sulfate concentrations in the Delta-Estuary are the Water Quality Objectives for electrical conductivity (EC) and the ratio of San Joaquin River to Sacramento River water. Both are controllable water quality factors and result from water management decisions made by the State of California. Table 3 of Water Rights Decision 95-1WR stipulates maximum ambient electrical conductivity values for various locations in the Delta by month and water year type (SWRCB, 1995). Electrical conductivity in the estuary is primarily a function of freshwater outflow and seawater intrusion.[9] Water Right Decision 95-1WR regulates electrical conductivity by specifying both the amount of freshwater outflow and the amount of water exported to Southern California. For example, during 2000-2001, the 2 o/oo salinity level[10] in ambient bottom water was located as far seaward as the City of Martinez in March 2000, but migrated as far upstream as Rio Vista in the summer of 2001 (Foe, 2003). The upstream movement of the salinity field had the effect of increasing sulfate concentrations in western Delta water by about ten-fold.

Sulfate concentrations are about seven times higher in the San Joaquin River than in the Sacramento River. At present, the San Joaquin River is almost entirely diverted out of the Delta by way of Old River and Grantline Canal for export to southern California via the State and Federal Pumping facilities near Tracy. This reduces the proportion of San Joaquin River water in much of the southern and central Delta and allows intrusion of Sacramento River water with lower sulfate concentrations. The Record of Decision for the CALFED Bay-Delta Program committed the State to evaluate and, if practical, begin construction of a series of permanent, operable barriers in the southern Delta to better control the routing of San Joaquin River water (CALFED Bay-Delta Program, 2004B). An indirect consequence of the permanent barriers is that their operation will determine sulfate concentrations in much of the central and southern Delta.

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[8] Dissolved, neutrally charged mercury is the only form that readily crosses microbial cell membranes.

[9] Sulfate concentrations in the Sacramento and San Joaquin Rivers varied between 6-14 and 42-108 mg/l in 2000 and 2001 (Foe, 2003) while full strength seawater is 2,700 mg/l (Parsons and Takahashi, 1975).

[10] Salinity is generally reported in terms of parts per thousand (abbreviated o/oo), the number of pounds of salt per 1,000 pounds of water.

Sulfate amendment studies need to be undertaken with sediment collected throughout the year from the southern, central and western Delta to determine whether the sulfate concentration in the overlying water affect methylmercury production in sediment. Results of these experiments can be considered when evaluating how to manage the permanent, operable barriers in the southern Delta and when considering water right decisions to modify the location of the salinity field in the estuary.

3.2 New Water Impoundments

The creation of new water impoundments has been found to stimulate sediment microbial activity and to increase methylmercury concentrations in sediment, water and biota (Verdon *et al.*, 1991; Bodaly *et al.*, 1997). The State of California has a growing population and a limited water supply for municipal and agricultural use. One alternative under evaluation is the construction of additional reservoir storage. The Record of Decision for the CALFED Bay-Delta Program directs agencies and local interests to continue to evaluate five surface water storage options to improve water management (CALFED Bay-Delta Program, 2004A). These include north of Delta off-stream storage, in-Delta storage, Shasta Lake expansion, Los Vaqueros Reservoir expansion and upper San Joaquin storage. Environmental planning for each project is underway and should evaluate the potential of each new facility to increase downstream methylmercury concentrations in the Delta.

3.3 Sediment Mercury Concentrations

Methylmercury production has been found to be a function of the total mercury content of the sediment. Methylmercury concentrations[11] adjusted for the organic content of the sediment increased logarithmically with increasing total mercury concentration in a study of 106 sites from 21 basins across the United States (Krabbenhoft *et al.*, 1999). The slope of the relationship was linear to approximately 1 mg/kg total mercury before commencing to asymptote. Similar linear relationships have been observed in the Delta between methyl and total mercury concentrations in sediment (Table 3.1). The statistical significance of the correlation increases when data from one land use type (e.g., marshes) are used. This implies that methylation rates may also be a function of habitat type. The results are consistent with laboratory experiments where increasing concentrations of inorganic mercury were amended into sediment and the evolution of methylmercury monitored. The efficiency of the conversion of total to methylmercury was linear to about 1 mg/kg before commencing to level off (Bloom, 2003; Rudd *et al.*, 1983).

[11] Radiotracer experiments in Florida Everglade sediment demonstrate that methylmercury production is positively correlated with bulk sediment methylmercury concentrations (Gilmour *et al.*, 1998). Moreover, the spatial pattern of methylmercury production was strongly correlated with aqueous and biotic concentrations, suggesting that surficial sediment concentrations could be used as an analog for *in situ* methylmercury production and flux into the overlying water. Bulk methylmercury sediment concentrations are now widely used as an index of methylmercury production (Krabbenhoft *et al.*, 1999; Bloom *et al.*, 1999 and 2003; Heim *et al.*, 2002; Slotton *et al.*, 2002; Conaway *et al.*, 2003; Benoit *et al.*, 1999).

Table 3.1: Field Studies Demonstrating a Positive Correlation Between Total and Methylmercury in Freshwater Surficial Sediment

Location (a)	R^2	**P-Value**	**Comments**	**Author**
Sacramento-San Joaquin Delta Estuary	0.2	<0.01	All habitats in Delta combined.	Heim *et al.*, 2003
Sacramento-San Joaquin Delta Estuary	0.52	<0.001	Only marsh habitats.	Heim *et al.*, 2003
Sacramento-San Joaquin Delta Estuary	0.37	<0.001	Comparisons inside and outside of flooded Delta Islands.	Slotton *et al.*, 2003
Elbe River	0.69	<0.0001	Germany.	Hintelmann & Wilken, 1995
Patuxent River Estuary	0.61	<0.05	Sub embayment of Chesapeake Bay.	Benoit *et al.*, 1998
National Survey	0.62	<0.0001	Log/log relationship normalized to percent organic carbon at 106 sites in 21 basins across the United States.	Krabbenhoft *et al.*, 1999
Lake Levrasjon	0.64	<0.05	Southern Sweden.	Regnell *et al.*, 1997

(a) The majority of the sediment in each study had a mercury content less than 1 ppm.

Mercury concentrations in fish at contaminated sites decline after control measures are instituted to reduce incoming mercury loads (Table 3.2). Most sites studied to date are industrial facilities that discharge to fresh water and have operated for relatively short periods.[12] The initial decrease in fish tissue concentration near the source of contamination is often fast with about a 50% decline in the first five to ten years. However, after a rapid initial decrease, concentrations tend to stabilize with little, if any, subsequent decline (Turner & Southworth, 1999; Takizawa, 2000; Lodenius, 1991; Lindestrom, 2001; Francesconi *et al*., 1997). The new equilibrium value is usually higher than in adjoining uncontaminated waterways and is also often greater than what is recommended as safe for human consumption (Turner & Southworth, 1999; Parks & Hamilton, 1987; Lodenius, 1991; Lindestrom, 2001; Francesconi *et al*., 1997; Becker & Bigham, 1995). The reasons are unclear but may be because small amounts of mercury are still entering from terrestrial sources (Turner and Southworth, 1999) or because of difficulties in bringing sediment concentrations down to background levels (Francesconi *et al*., 1997; Jernelov & Asell, 1975). If contamination has spread to areas more distant than the immediate facility, then reductions in fish tissue concentrations are much slower (Southworth *et al*., 2000). Absent from the literature are reports on remediation of pollution from mercury mining. The magnitude and duration of mercury and gold mining in California, coupled with the extensive distribution of contamination, will likely make recovery much slower than at industrial sites (Table 3.2).

As part of the mercury control program for San Francisco Bay, San Francisco Water Board staff established a goal for Bay sediment of 0.2 mg/kg mercury and assigned Central Valley outflows a total mercury load reduction of 110 kg per year to achieve it (Johnson & Looker, 2004). Waterborne mercury and total suspended sediment loads in the Delta's tributaries are summarized in Chapter 7. Initial

[12] One to two decades.

Table 3.2: Change in Fish Tissue Mercury Concentration After Initiation of Source Control.

Location	Mercury Source	Biotic Change	Control Measures	References
Oak Ridge National Laboratory, Tennessee	Weapons Facility	Sunfish at discharge point declined from 2 to 1 mg/kg in 5 yrs; half mile downstream sunfish declined from 0.9 to 0.7 mg/kg in 9 yrs; no change in tissue 2 and 5 miles downstream.	Reduced discharge, excavated portion of flood plain.	Turner & Southworth, 1999; Southworth *et al.*, 2000
Lake St. Clair, Michigan	Two Chloralkali Plants	Walleye fish declined from 2.3 to 0.5 mg/kg in 25 yrs	Reduced/eliminated discharge	Turner & Southworth, 1999.
Abbotts Creek, North Carolina	Battery Manufacturing plant	Fish declined from 1 to 0.5 mg/kg in 11 yrs	Treated groundwater, reduced/eliminated discharge, removed contaminated soil, natural sediment burial	Turner & Southworth, 1999
Saltville, Virginia	Chloralkali Plant	Rockfish declined from 3.5 to 1 mg/kg in 20 yrs	River sediment dredged, rock bottom grouted, rip-rap river bank, pond seepage treated with activated carbon	Turner & Southworth, 1999
Howe Sound, British Columbia, Canada	Chloralkali Plant	Dungeness crab declined from 2 to 0.2 mg/kg in 5 yrs. No subsequent change	Reduced/eliminated discharge, treated groundwater	Turner & Southworth. 1999
Little Rock Lake, Wisconsin	Atmospheric deposition	Yellow Perch declined 30% in 6 yrs	Reduced atmospheric mercury input by 60%.	Hrabik & Watras, 2002.
Minimata, Japan	Chloralkali Plant	Fish declined from 9.0 to 0.4 mg/kg in 8 yrs; no further change.	Eliminated discharge; dredged and disposed of sediment.	Takizawa, 2000
Clay Lake, Ontario, Canada	A chloralkali plant and a wood pulp mill.	Walleye fish declined from 15.1 to 2.0 mg/kg in 20 yrs. Background concentration is 0.6 mg/kg.	Eliminated discharge; natural burial of contaminated sediment	Parks & Hamilton, 1987; Turner & Southworth, 1999.
Ball Lake, Ontario, Canada (downstream of Clay Lake)	Same as above	Walleye fish declined from 2.0 to 1.4 mg/kg in first 5 yrs. Northern Pike from 5.1 to 1.8 mg/kg. No change in Lake Whitefish.	Same as above	Armstrong & Scott, 1979
Lake Kirkkojarvi, Finland	Phenylmercury in slimicide in pulp mill	4 and 1-kg Northern Pike declined from 3.6 to 2.1 and from 1.5 to 0.8 mg/kg in 20 yrs. All reductions happened in first 10 yrs. Background concentration in 1-kg pike is 0.4 mg/kg.	Reduced discharge, natural burial	Lodenius, 1991
Lake Vanern, Sweden	Chloralkali Plant	5-yr old Northern Pike declined from 1.4 to 0.6 mg/kg in 25 yrs. Most of decrease occurred in first 10-15 yrs. Background concentrations in Pike are 0.4 mg/kg	Reduced/eliminated discharge, natural burial	Lindestrom, 2001
Princess Royal Harbor, Australia (Marine water)	Superphosphate Processing Plant	Mercury in 8 marine fish species declined by about 50% in 9-yrs. Most of decrease happened in first 4-yrs. Tissue concentrations are still about twice background.	Eliminated discharge, natural burial	Francesconi *et al*., 1997
Onondaga Lake, New York	Municipal and industrial discharge	Mercury in six fish species declined by 60 to 80 % in 22 yrs. Tissue concentrations are still about twice background.	Eliminated discharge, natural burial	Becker & Bigham, 1995.
North Carolina, Quebec, Finland, Manitoba, Labrador and Newfoundland	Reservoir creation	Fish tissue levels declined to normal after 3 to 30 years.	None	As reviewed in French *et al*., 1998.

management actions of the Delta mercury TMDL could consider controlling mercury from watersheds with high methylmercury concentrations in fish, high mercury to suspended sediment ratios and large areas of downstream marsh. The initial goal would be to meet the San Francisco Water Board's goal of 110 kg total mercury reduction per year, but additional load reductions eventually may be needed to achieve compliance with the Central Valley Water Board's proposed fish tissue targets for the Delta (Chapter 4).

3.4 Forms of Mercury

Two different forms of mercury are transported into the Delta with potentially different methylation rates. The first form is mercury mine waste from the Coast Range. Most of this material is thought to be mercuric sulfide, cinnabar and metacinnabar (Bloom, 2003). Mercury mine waste enters the Delta from mine-impacted coast range creeks such as Putah and Cache Creeks. The second form is elemental mercury lost from placer gold mining operations in the Sierra Nevada Mountains. Elemental mercury enters the Delta in Sacramento, Mokelumne and San Joaquin River water that drains from the northern and southern gold fields.

Mercury from gold mining appears to be more biologically available than material from mercury mines. The evidence is twofold. First, Frontier Geosciences conducted a 1-year microcosm incubation study with both gold and mercury mine waste to determine the relative methylation efficiency of each (Bloom, 2003). Mercury from gold mining was found to have the higher methylation rate. Second, the ratio of methyl to total mercury in natural sediment is assumed to be a field measure of methylation efficiency (Gilmour *et al.*, 1998; Krabbenhoft *et al.*, 1999; Bloom *et al.*, 1999 and 2003). Heim and others (2003) collected sediment at multiple locations in Cache Creek (representative of mercury mine waste) and the Cosumnes River (representative of gold mine material) on three occasions (October 1999, May 2001 and October 2001) to determine methyl and total mercury concentrations and methylation efficiencies. The highest methyl to total mercury ratios were consistently observed in Cosumnes River material. These results are consistent with the conclusions of Bloom (2003) and suggest that floured elemental mercury from gold mining in the Sierra Nevada is more readily methylated than is cinnabar from the Coast Range.

Heim and others (2003) also collected sediment samples at multiple locations in Cache Creek. The ratio of methylmercury to total mercury increased with increasing distance from the mercury mining districts. The authors speculate that diagenic weathering-type processes are changing the form of the mercury and increasing its methylation efficiency as the material is slowly transported away from the mines. The precise mechanisms are not known but may include the formation of soluble polysulfide complexes (Paquette & Heltz, 1995) and dissolution of cinnabar by humic and fulvic acids (Wallschlaeger *et al.*, 1998; Ravichandran *et al.* 1998). Both processes should increase the efficiency of the conversion of inorganic to organic mercury. No similar weathering type experiments have been conducted on Sierra Nevada gold mine-derived mercury. The Cache Creek findings suggest that there is currently insufficient understanding of mercury weathering processes to justify developing control programs that preferentially target controlling gold-mine waste material.

3.5 Wetlands

Research in the Delta and elsewhere has found that wetlands are sites of efficient methylmercury production (Slotton *et al.*, 2003; Heim *et al.*, 2003; St. Louis *et al.*, 1994, 1996; Gilmour *et al.*, 1998). In fact, one of the best predictors of methylmercury concentrations in water and in biota is the amount of wetland present in upstream watersheds (Krabbenhoft *et al.*, 1999; Wiener *et al.*, 2002). The Record of Decision for the CALFED Bay-Delta Program commits the Authority to restore 30,000 to 45,000 acres of fresh, emergent tidal wetlands in the Delta by 2030 (CALFED Bay-Delta Program, 2000a). Many of the proposed sites are downstream of mercury-enriched watersheds. Marsh restoration efforts below mercury enriched watersheds are proposed for the following locations: Yolo Bypass downstream of Cache and Putah Creeks; Dutch Flats downstream of the Mount Diablo Mercury mine in the Marsh Creek watershed; and Staten Island and the Cosumnes River Wildlife Refuge near the confluence of the Cosumnes River and Mokelumne River. Extensive restoration efforts in the Delta have the potential to increase methylmercury exposure for people and wildlife.

Key Points

- The problem with mercury in the Delta's aquatic ecosystems can be defined as biotic exposure to methylmercury. Therefore, decreasing biotic exposure to methylmercury is the ultimate goal of the Delta methylmercury TMDL and implementation program.
- The implementation plan could focus on sources and processes that are potentially controllable in the Delta. Potentially controllable sediment factors and landscape events important in net methylmercury production include: water rights salt standards in the Delta; creation of new water impoundments; amount of inorganic mercury present in the sediment; and amount of permanent or seasonally flooded wetland in a watershed.

4 NUMERIC TARGETS

Water quality targets for mercury were calculated to protect beneficial uses of the water and aquatic resources of the Delta. The targets are intended to reduce the risks to humans and wildlife that consume fish and other aquatic organisms from the Delta that contain methylmercury. This chapter first describes the derivation of species-specific targets based on a suite of fish types to protect humans and wildlife. The Central Valley Water Board staff proposes three targets for the protection of human and wildlife health: 0.24 mg/kg (wet weight) in muscle tissue of large trophic level four (TL4) fish such as bass and catfish; 0.08 mg/kg (wet weight) in muscle tissue of large TL3 fish such as carp and salmon; and 0.03 mg/kg (wet weight) in whole trophic level 2 and 3 fish less than 50 mm in length. In addition, staff proposes an implementation goal of 0.24 mg/kg methylmercury, wet weight, in standard 350-mm largemouth bass. As described in Chapter 5, this implementation goal can be linked to aqueous methylmercury to develop an implementation goal for methylmercury in unfiltered ambient water, which in turn can be used to determine methylmercury source reductions needed to achieve the proposed target for methylmercury in fish.

In addition to addressing sources of methylmercury to the Delta, the Delta mercury control program addresses total mercury sources to the Delta and San Francisco Bay. The San Francisco Bay TMDL assigns a load reduction of 110 kg per year from the Central Valley (Johnson & Looker, 2004). As described in later chapters of this report, the mercury control program for the Delta is designed to achieve the total mercury load reduction required by the San Francisco Water Board, as well as to maintain compliance with the USEPA's CTR for total mercury in freshwater sources and to limit total mercury sources to the Delta to ensure that methylmercury levels in fish do not increase in the future.

4.1 Definition of a Numeric Target

Numeric targets are the specific goals for the TMDL that will enable the protection of the beneficial uses of the Delta and San Francisco Bay. The development of numeric targets involves the following elements:

- Identification of the target media and the basis for using the selected target media to interpret or apply applicable water quality standards.
- Identification of target levels for the selected target media and the technical basis for the target levels.
- Comparison of historical or existing conditions and desired future conditions for the target media selected for the TMDL.

4.2 Clean Water Act 303(d) Listing and Beneficial Use Impairment

The California Department of Health Services has issued health advisories recommending that consumers limit their consumption of striped bass and sturgeon from the Delta and Bay because of high methylmercury tissue concentrations (Section 2.4.1). The fish advisory resulted in the Central Valley and San Francisco Water Boards listing the Bay-Delta Estuary as impaired.

By definition, an impaired water body does not support all of its designated beneficial uses. Existing and potential beneficial uses are listed in Table 2.3 in Chapter 2. The Delta provides habitat for warm and cold water species of fish and the aquatic communities associated with them. In addition, the Delta and associated riparian areas provide valuable wildlife habitat. Beneficial uses that are impaired due to high mercury levels include commercial and sport fishing and wildlife habitat.

4.3 Selection of the Type of Target for the Delta

4.3.1 Fish Tissue

Measurements of mercury in the target media should be able to assess fairly directly whether beneficial uses are being met. Several media for numeric targets were considered, including sediment, water column and biota. The major beneficial use of the Delta that is currently unmet is its use as a safe fishery for humans and wildlife. A target of mercury in fish tissue was determined to be the most appropriate because it provides the most direct assessment of fishery conditions and improvement. Fish tissue data have been collected between 1969 and 2002 in the Delta. Existing data for fish species consumed by humans and wildlife provide a baseline against which future improvements can be measured.

Targets are developed for **methylmercury** in fish tissue because it is the most toxic form of mercury. It is also the form to which humans and wildlife may be exposed in the Delta at levels sufficient to cause adverse effects. The cost for methylmercury analysis is greater than that for total mercury; therefore, most data available are for total mercury in fish tissue. Independent research demonstrates that most mercury (85-100%) in fish muscle is methylmercury (Becker and Bigham, 1995; Slotton *et al.*, 2003). For the purposes of the TMDL, Central Valley Water Board staff assumes that all the mercury measured in fish is methylmercury.

4.3.2 San Francisco Bay Numeric Target

The Delta TMDL is also structured to meet the San Francisco Bay mercury TMDL's total mercury allocation for Central Valley outflows to the Bay. San Francisco Water Board staff developed a target for San Francisco Bay sediment mercury concentration of 0.2 mg/kg and assigned the Central Valley a five-year average total mercury load allocation of 330 kg/yr at Mallard Island or a decrease of 110 kg/yr in mercury sources to the Delta. The San Francisco Bay mercury TMDL staff report provides a detailed derivation of the San Francisco Bay sediment target and allocation for the Central Valley (Johnson & Looker, 2004). Strategies for reducing the total mercury loading to San Francisco Bay are discussed in Chapter 8 in this TMDL report and Chapter 4 in the Proposed Basin Plan Amendment draft staff report.

4.3.3 Water Criteria

The California Toxics Rule (CTR) mercury criterion applies to the Delta (see Section 2.3.2.2). This criterion of 50 ng/l total recoverable mercury in water is intended to protect the health of humans consuming contaminated organisms and drinking water. The CTR value may not be sufficiently protective of humans consuming fish from the Delta because of the low bioconcentration factors used to derive the CTR value. Central Valley Water Board staff considers fish tissue targets to be more stringent than the CTR criterion.[13] Although the CTR criterion may be less protective than the fish tissue targets discussed below, the TMDL was developed to comply with the CTR mercury criterion. Compliance with the CTR criterion through the TMDL is discussed in the total mercury source assessment (Chapter 7) and total mercury limits (Chapter 8) sections of this report.

4.4 Fish Tissue Target Equation and Development

Key variables that are incorporated into the calculation of fish tissue targets are:

- Acceptable daily dose level of methylmercury;
- Body weight (bwt) of the consumer;
- Trophic level or size of fish consumed; and
- Rate of fish consumption.

These components can be related using a basic equation (OEHHA, 2000; USEPA, 1995c) as follows.

Equation 4.1:

$$\frac{\text{Safe daily intake} * \text{Consumer's body weight}}{\text{Consumption rate}} = \text{Acceptable level of mercury in fish tissue}$$

At or below the safe daily intake of methylmercury, consumers are expected to be protected from adverse effects. An acceptable intake level is also called a reference dose (RfD). An RfD is expressed as an average daily rate (micrograms of mercury per kilogram body weight per day) of mercury intake. In general, an RfD is calculated by using studies of exposure in specific populations to determine a threshold level of exposure below which adverse effects did not occur. The threshold level is then divided by uncertainty factors that lower the value to the final reference dose. Uncertainty factors account for differences in metabolism and sensitivity between individuals, lack of toxicity information in available studies, or other unknowns.

In calculation of its recommended methylmercury criterion to protect human health, USEPA added a relative source contribution (RSC) component to the equation to account for methylmercury from other sources (USEPA, 2001). Humans are exposed to methylmercury from commercial fish as well as locally caught fish. Human intakes of methylmercury from all other sources (air, drinking water, soil, and foods other than fish and seafood) are considered negligible. The RSC represents that portion of methylmercury exposure that will not be controlled by cleanup actions directed to a particular water body. Because piscivorous wildlife species are assumed to obtain all of their fish or other aquatic prey from the local water body, no RSC adjustment is used for the wildlife calculations. As with humans, the direct intake of methylmercury by piscivorous wildlife from air or water is negligible relative to intake from fish and aquatic organisms (USEPA, 1997a).

[13] The weighted average practical bioconcentration factor (PBCF) used to develop the CTR mercury criterion is 7342.6 (USEPA, 2000). For the Delta, bioaccumulation factors (BAF) for large trophic 4 fish are in the range of 50,000 to 300,000. These BAF are the ratios of mercury in fish to the concentration of total recoverable mercury in water. The Delta bioaccumulation factors indicate that piscivorous fish species in the Delta accumulate higher concentrations of mercury than USEPA's PBCF.

The consumption rate can be separated into rates of consumption of fish from each trophic level. Adjusting for multiple consumption rates and the RSC, the basic equation appears as follows.

Equation 4.2:

$$\frac{(\text{Safe intake} - \text{RSC}) * \text{body weight}}{(\text{CRate}_{TL2} + \text{CRate}_{TL3} + \text{CRate}_{TL4})} = \text{Acceptable level of mercury in Delta fish tissue}$$

Where: CRate_{TL2} = consumption rate of fish from Trophic Level 2
CRate_{TL3} = consumption rate of fish from Trophic Level 3
CRate_{TL4} = consumption rate of fish from Trophic Level 4

Safe levels of methylmercury in fish tissue that protect wildlife are presented first in this report, followed by the human health targets. The order of presentation and in-depth discussion of wildlife methodology are not intended to suggest greater importance of wildlife targets relative to human health targets. Rather, wildlife targets are discussed first because the safe fish tissue levels are based on average consumption rates that are assumed to be constant. Human consumption rates, however, vary widely by individual. For targets to protect human consumers, consumption rate options are incorporated into the calculation.

4.5 Wildlife Health Targets

Birds and mammals most likely at risk for mercury toxicity are primarily or exclusively piscivorous. Those identified for the Delta are: American mink, river otter, bald eagle, kingfisher, osprey, western grebe, common merganser, peregrine falcon, double crested cormorant, California least tern, and western snowy plover[14] (USEPA, 1997a; CDFG, 2002). Bald eagles, California least terns and peregrine falcons are listed by the State of California or by USEPA as either threatened or endangered species. The Delta is a foraging and possible wintering habitat for bald eagles (USFWS, 2004). California least terns also forage in the Delta. There is at least one nesting colony of these terns within the Delta (USFWS, 2004). Although most of the Delta habitat is unlike that preferred by peregrine falcons for nesting, several peregrine falcon pairs have nested on bridges in the area (Linthicum, 2003).

Acceptable fish tissue levels of mercury for wildlife species can be calculated using daily intake levels, body weights and consumption rates. Parameters needed to estimate daily methylmercury exposures and safe levels of methylmercury in prey for wildlife are given in Table 4.1. Mercury studies conducted in the laboratory and field are used to derive RfD for birds and mammalian wildlife. The following section uses these RfDs to calculate fish tissue targets to protect the health of wildlife in the Delta.

4.5.1 Reference Doses, Body Weights & Consumption Rates

The reference dose for mammalian wildlife species of 0.018 mg methylmercury/kg bwt/day is based on studies in which mink were fed methylmercury at varying doses and evaluated for neurological damage,

[14] The CDFG *California Wildlife Habitat Relationships* database also reports observations of brown pelicans and clapper rails in the Delta. Both of these species are federally listed as endangered and depend on the aquatic food web. However, it has been confirmed that brown pelicans and clapper rails prefer salt water habitats and are only occasional visitors to the Delta regions as discussed in this TMDL (Schwarzbach, 2003; CDFG, 2005). Peregrine falcon are included because they consume piscivorous waterfowl.

growth and survival (USEPA, 1995a; USEPA, 1997b). Studies of mallard growth and reproduction following methylmercury exposure were used to determine a methylmercury reference dose for birds of 0.021 mg/kg bwt/day (USEPA, 1997b).

Average body weights of adult females are used because the most sensitive endpoints of methylmercury toxicity are related to reproductive success. The USFWS provided guidance to Central Valley Water Board staff regarding the species of concern and their exposure parameters (USFWS, 2002, 2003 & 2004).

4.5.2 Safe Methylmercury Levels in Total Diet

Levels of mercury in fish tissue that would result in methylmercury intakes by piscivorous wildlife at or below safe intake levels are calculated in two steps. First, safe levels of methylmercury in the total diet of each wildlife species are calculated (Table 4.2). The total diet safe level represents the concentration of methylmercury, as an average in all prey consumed, needed to keep the organism's daily intake of methylmercury below the reference dose. Total diet safe levels were calculated using the exposure parameters for wildlife species and Equation 4.1. In the second step, the total diet safe level is translated into protective levels of methylmercury in various components of an organism's diet (Table 4.3). An example calculation of the total safe diet level for mink is shown below:

$$\frac{\text{Mammalian reference dose} * \text{Mink body weight}}{\text{Mink fish consumption rate}} = \text{Total diet safe level}$$

$$\frac{18\ \mu\text{g MeHg/kg day} * 0.60\ \text{kg}}{140\ \text{g/day}} = 0.077\ \mu\text{g MeHg/g total diet (0.077 mg/kg)}$$

4.5.3 Calculation of Safe Fish Tissue Levels from Total Diet Values

Wildlife species consume fish and other aquatic prey from various size ranges and trophic levels. In the second step of wildlife target development, safe fish tissue levels are identified for different prey classifications. These classifications are termed "trophic level food groups". Table 4.3 shows safe fish tissue concentrations needed by the wildlife species and developed for prey within the following trophic level food groups: TL 2 fish less than 50 mm in length, TL2 and 3 fish of 50-150 mm, TL3 fish of 150-350 mm, and TL4 fish greater than 150 mm.

In cases in which an organism's prey is fairly uniform and from one trophic level, the total diet safe level becomes the average, safe tissue concentration. For organisms that feed from different trophic levels, the proportions of each trophic level in the diet (Table 4.1) are used to determine safe tissue levels for each component of the diet. The species whose prey falls generally into one size category are: mink, California least tern, western snowy plover, double crested cormorant, western grebe, kingfisher and

Table 4.1: Exposure Parameters for Fish-Eating Wildlife

Species (a)	**Body weight** (b) kg	**Total Food Ingestion Rate** (c) g/day, wet wt	**Trophic Level 2 Aquatic Prey** g/day, as % of diet	**Trophic Level 3 Aquatic Prey** g/day, as % of diet	**Trophic Level 4 Aquatic Prey** g/day, as % of diet	**Piscivorous Bird Prey** g/day, as % of diet	**Omnivorous Bird Prey** g/day, as % of diet	**Other Foods** (d) g/day, as % of diet	**Size of Prey**
Mink	0.60	140	-	140 (100%)	-	-	-	-	most prey 50-150mm; females catch smaller prey than males (USEPA, 1995b)
River otter	6.70	1124	-	899 (80%)	225 (20%)	-	-	-	heterogeneous, 20-500 mm (USEPA, 1995b); majority <150 mm but commonly catch large TL4 fish.
California least tern	0.045	31	-	31 (100%)	-	-	-	-	mostly < 50 cm, nearly all fish
Western snowy plover	0.041	33.3	8.3 (25%)	-	-	-	-	25 (75%)	mainly aquatic and terrestrial invertebrates. Assume TL2 aquatic prey is 25% of diet; (USFWS, 2003)
Belted kingfisher	0.15	68	-	68 (100%)	-	-		-	generally less than 105 mm; up to 180 mm (Hamas, 1994)
Common merganser (e)	1.23	302	-	302(100%)	-	-	-	-	most prey <150 mm (USEPA,1995b; Hatch & Weseloh, 1999)
Double-crested cormorant (f)	1.74	390	-	390 (100%)	-	-	-	-	generally 100-300 mm length; up to 360mm (Mallory & Metz, 1999)
Western grebe (g)	1.19	296	-	296 (100%)	-	-	-	-	USFWS assumed similar to merganser (USFWS, 2004)
Bald eagle (h)	5.25	566	-	328 (58%)	74 (13%)	28 (5%)	74 (13%)	62 (11%)	fish 75-500+ mm; most will be >150 mm (Jackman, 1999; USEPA, 1995b).
Osprey (i)	1.75	350	-	315 (90%)	35 (10%)	-	-	-	fish 100-450 mm; most will be >200 mm.
Peregrine falcon (j)	0.89	134	-	-	-	6.7 (5%)	13.4 (10%)	114 (85%)	Does not eat fish.

Table 4.1 Footnotes:

(a) Italics denote species listed as threatened or endangered by State or Federal authorities.
(b) Average female body weights are from *Trophic Level and Exposure Analyses for Selected Piscivorous Birds and Mammals Volume II* (USEPA, 1995b), USFWS (2003, 2004), and as noted below.
(c) Total food ingestion rates are from USEPA (1995b) and USFWS (2003; 2004) and as noted below.
(d) Other foods are mainly terrestrial mammal, bird, reptile and invertebrate prey that are presumed to provide negligible amounts of methylmercury.
(e) Merganser body weight and ingestion rate from Schwarzbach and others (2001).
(f) Cormorant body weight is the average for female birds cited in Hatch and Weseloh (1999). This paper also reports daily consumption at 20-25% of body mass. Total ingestion rate of 390 g/day is 22.5% of average female bodyweight.
(g) Female western grebe body weight from Storer and Nuechterlein (1992).
(h) Bald eagle parameters provided by the USFWS (2004). Diet of bald eagles in northern California includes fish, mammals and birds. Using dietary data from Jackman and others (1999), the USFWS estimated the average proportions of prey types. TL3 and TL4 fish comprised 58% and 13% of the total bald eagle diet, respectively. Piscivorous birds, such as gulls, grebes, and mergansers, comprised approximately 5% of the total diet. An additional 13% of the total diet was comprised of other aquatic birds, such as coots, that feed mainly on TL2 organisms. Bald eagles are scavengers and thus consume fish of large sizes (Jackman *et al.*, 1999).
(i) Osprey catch and eat large fish, the majority of which are >200 mm (USEPA, 1995b). In a water body where TL4 sport fish are readily available, osprey diet is assumed to be 10% TL4 fish (USFWS, 2002). Prey size is limited to the maximum size that an osprey can lift out of water.
(j) Peregrine falcons eat a wide variety of birds, including grebes, herons, shorebirds, mergansers, gulls and other birds that accumulate methylmercury from the aquatic food web. USFWS (2004) supports the assumption by Central Valley Water Board staff that approximately 15% of peregrine prey in the Delta area is comprised of piscivorous birds. See the appendices of the Cache Creek TMDL for Mercury for further analysis of peregrine prey and habitat. Available at: http://www.swrcb.ca.gov/rwqcb5/programs/tmdl/Cache-SulphurCreek/index.html.

Table 4.2: Concentrations of Methylmercury in Total Diet to Protect Delta Wildlife Species

Species	**RfD** (µg/kg bwt-day)	**Body Weight** (kg)	**Total Food Ingestion Rate** (g/day)	**Safe Methylmercury Concentration in Total Diet** (mg/kg in diet)
Mink	18	0.60	140	0.077
River otter	18	6.70	1124	0.11
California least tern	21	0.045	31	0.030
Western snowy plover	21	0.041	33.3	0.026
Belted kingfisher	21	0.15	68	0.046
Common merganser	21	1.23	302	0.086
Double-crested cormorant	21	1.74	390	0.094
Western grebe	21	1.19	296	0.084
Bald eagle	21	5.25	566	0.20
Osprey	21	1.75	350	0.11
Peregrine falcon	21	0.89	134	0.14

Table 4.3: Safe Concentrations of Methylmercury in Fish (mg/kg) by Trophic Level to Protect Wildlife

Species (a)	**TL 2, < 50 mm**	**TL 2-3, 50-150 mm**	**TL 3, 150-350 mm**	**TL 4, 150-350 mm**	**TL 3, >150 mm**	**TL 4, >150 mm**
Mink		0.08				
River otter		0.04		0.36		
California least tern	0.03					
Western snowy plover (b)	0.10					
Belted kingfisher		0.05				
Double-crested cormorant		0.09				
Common merganser			0.09			
Western grebe			0.08			
Osprey			0.09	0.26		
Bald eagle (c)					0.11	0.31
Peregrine falcon (d)			(0.17)			

(a) Italics denote species that are listed as threatened or endangered by federal or State authorities.
(b) The snowy plover safe level should be applied to TL2/3 aquatic invertebrates, such as small clams, crabs, polychaetes and amphipods.
(c) To avoid exceeding the bald eagle wildlife value, safe concentrations must be attained in birds as well as fish eaten by bald eagles. The safe levels for average mercury concentrations in omnivorous and piscivorous bird prey are 0.19 and 1.35 mg/kg, respectively. Because bald eagles are scavengers, there is no upper size limit on fish eaten by these birds.
(d) Parentheses denote the TL3 fish level corresponding to the piscivorous bird safe concentration for peregrines. For birds eaten by peregrine falcons, the average concentrations should not exceed 2.2 mg/kg in piscivorous bird prey, respectively.

common merganser. For these species, the total diet safe level becomes the safe fish tissue level matched to the size and trophic level of prey consumed.

Average, safe fish tissue concentrations for kingfisher, cormorant and mink were determined for the food group size range of 50-150 mm. Although kingfishers typically consume fish less than 105 mm in length, they can eat fish as long as 180 mm (Hamas, 1994; USEPA, 1995b). The range for cormorant prey is 30 to 400 mm, with most fish eaten being less than 150 mm (Hatch and Weseloh, 1999). Most fish caught by mink are in the range of 50-150 mm (USEPA, 1995b). As the size ranges of prey caught by these three species are similar, one category of TL2/3 fish is appropriate for their protection (USFWS, 2004).

A second food group of TL3 fish in the range of 150-350 mm incorporates safe fish tissue concentrations for prey of common mergansers and western grebes. Most prey caught by mergansers is in the range of 100-300 mm, with catches of fish up to 360 mm observed (Mallory and Metz, 1999). Because body size and foraging strategy of western grebes are similar to those of the merganser, staff assumed the same size range for grebe prey (USFWS, 2004).

Otter, bald eagle and osprey eat fish from multiple trophic level food groups. Methylmercury concentrations vary as a function of size and trophic level of prey. Therefore, different trophic levels of prey will have different acceptable concentrations of methylmercury. For these wildlife species, the total diet safe level (TDSL) can be described as:

Equation 4.3:

$$TDSL = (\%\ diet\ TL_2 * TL2_{conc}) + (\%\ diet\ TL_3 * TL3_{conc}) + (\%\ diet\ TL_4 * TL4_{conc})$$

Where: $\%$ diet TL_2 = percent of trophic level 2 biota in diet
$\%$ diet TL_3 = percent of trophic level 3 biota in diet
$\%$ diet TL_4 = percent of trophic level 4 biota in diet
$TL2_{conc}$ = concentration of methylmercury in TL2 biota
$TL3_{conc}$ = concentration of methylmercury in TL3 biota
$TL4_{conc}$ = concentration of methylmercury in TL4 biota

In order to solve the above equation for the desired concentrations in TL2, TL3 and TL4 biota, concentrations in two trophic levels are put in terms of the concentration in the lowest trophic level. Equation 4.3 is then rearranged to solve for the lowest trophic level concentration.

In order to express the concentration in a higher trophic level (i.e., TL4) in terms of TL2 concentrations, staff used two types of translators: food chain multipliers (FCM) and trophic level ratios (TLR).[15] FCM and TLR used in the calculation of Delta wildlife targets are shown in Table 4.4. Where possible, site-specific, existing fish concentration data was used to develop the ratios. A similar table of safe fish tissue concentrations to protect wildlife species using a national average bioaccumulation factor (BAF) between TL3 and TL4 of five is presented in Chapter 6 of Mercury Study Report to Congress Vol. 7 (USEPA, 1997b). Details regarding the calculation of the translators and their use were provided by the USFWS (2003 & 2004).

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[15] A food chain multiplier (FCM) is the ratio of methylmercury concentrations in fish of different trophic levels. A FCM represents the biomagnification of mercury between 2 successive levels of the food chain. The FCM is determined using mercury concentration data in fish in a predator-prey relationship. Example: the FCM for trophic level 4 fish is the ratio of methylmercury in large TL4 fish to methylmercury in small TL3 fish.

A trophic level ratio (TLR) is the ratio of methylmercury concentrations in fish of different trophic levels, but is derived using data for fish in the same size classification. For example, an osprey may consume sunfish (TL3) and bass (TL4). A 350 mm sunfish, though, is too large to be preyed upon by an equivalently-sized smallmouth bass. Therefore, the ratio of mercury concentration in TL4 to TL3 fish eaten by osprey is termed a TLR rather than a FCM.

Table 4.4: Food Chain Multipliers and Trophic Level Ratios for Delta Wildlife Target Development

Translator	Value	Source	Relevant Wildlife Species (a)
Trophic Level Ratio (TLR)			
TLR 4/3	3.0	Ratio between existing MeHg concentrations in large TL4 fish (150-350 mm length) and large TL3 fish (150-350 mm length). Calculated from Delta-wide average fish tissue levels; see Appendix B.	Bald eagle, osprey
Food Chain Multipliers (FCM)			
FCM 4/3	8.1	Ratio between existing MeHg concentrations in large TL4 fish (150-350 mm length) and small TL3 fish (50-150 mm). Calculated from Delta-wide average fish tissue levels; see Appendix B.	River otter
FCM 3/2	5.7	Ratio between MeHg concentrations in large TL3 fish and small TL2 fish. From USFWS (2004) based on national averages.	Bald eagle, peregrine falcon
FCM piscivorous birds (FCM PB)	12.5	Ratio between MeHg in piscivorous bird tissue and in small TL3 prey fish. From USFWS (2003).	Bald eagle, peregrine falcon
FCM omnivorous birds (FCM OB)	10	Ratio between MeHg in omnivorous bird tissue and in small, TL2/3 prey fish and other aquatic organisms. From USFWS (2003).	Bald eagle, peregrine falcon

(a) Wildlife species for which the translator is used to determine safe tissue levels

4.5.3.1 River Otter Safe Tissue Levels

To calculate the safe concentrations for otter, the safe concentrations in TL3 and TL4 fish need to be determined. In order to solve for these two variables using Equation 4.3, the TL4 fish concentration is expressed in terms of the TL3 fish concentration. River otters eat a wide range of prey sizes. Large fish in the otter diet likely prey on small fish that otter also eat. Therefore, the TL4 variable is expressed using the TL3 concentration and a food chain multiplier (FCM 4/3). From the Delta field data, staff determined that the methylmercury concentration in large TL4 fish is 8.1 times the concentration in small TL3 fish. Safe tissue levels in TL3 and TL4 fish for otter are determined by:

$$TDSL_{otter} = (\%\ dietTL_3 * TL3_{conc}) + (\%\ dietTL_4 * TL4_{conc})$$

$$\textit{Where: } TL4_{conc} = TL3_{conc} * FCM\ 4/3$$

$$0.107\ mg/kg = (0.8 * TL3_{conc}) + (0.2 * 8.1 * TL3_{conc})$$

Solving for $TL3_{conc}$:

$$TL3_{conc} = 0.04\ mg\ MeHg/kg\ fish$$

$$TL4_{conc} = 0.04\ mg/kg * 8.1 = 0.36\ mg\ MeHg/kg\ fish$$

4.5.3.2 *Osprey safe tissue levels*

Safe methylmercury tissue levels for osprey are calculated like those for river otter, with the exception of the trophic level translator. Trophic level 3 and 4 fish eaten by osprey tend to be of similar sizes. Because there is not a food chain relationship between similarly sized fish, the osprey values are calculated using a trophic level ratio (TLR 4/3). On average in the Delta, methylmercury levels in large TL4 fish are 3.0 times the levels in large TL3 fish.

$$TDSL_{osprey} = (\%\ dietTL_3 * TL3_{conc}) + (\%\ dietTL_4 * TL4_{conc})$$

Where: $TL4_{conc} = TL3_{conc} * TLR\ 4/3$

$$0.105\ mg/kg = (0.9 * TL3_{conc}) + (0.1 * 3.0 * TL3_{conc})$$

Solving for $TL3_{conc}$:

$$TL3_{conc} = 0.088\ mg\ MeHg/kg\ fish$$

$$TL4_{conc} = 0.088\ mg/kg * 3.0 = 0.26\ mg\ MeHg/kg\ fish$$

4.5.3.3 *Bald Eagle Safe Tissue Levels*

Calculation of methylmercury tissue levels for bald eagle is slightly more complicated because bald eagles consume omnivorous birds (OB), piscivorous birds (PB), and fish. The omnivorous birds of concern in the bald eagle diet feed on trophic level 2 aquatic prey (mostly invertebrates). To solve the equation, safe tissue concentrations in the other eagle prey types are expressed in terms of the lowest food chain level (TL2) common to all prey types (USFWS, 2004). To translate the TL2 concentration into the piscivorous bird safe level, staff used the food chain multiplier for TL3 small fish (FCM 3/2) and the food chain multiplier relating piscivorous birds and small TL3 fish (FCM PB). Like osprey, bald eagles tend to eat TL3 and TL4 fish of similar size, hence the use of the TL4/3 ratio.

$$TDSL_{bald\ eagle} = (\%\ dietTL_3 * TL3_{conc}) + (\%\ dietTL_4 * TL4_{conc}) + (\%diet_{OB} * OB_{conc}) + (\%diet_{PB} * PB_{conc})$$

Where: $TL3_{conc\ large\ fish} = TL2_{conc} * FCM\ 3/2$

$$TL4_{conc\ large\ fish} = TL2_{conc} * FCM\ 3/2 * TL\ 4/3$$

$$OB_{conc} = TL2_{conc} * FCM\ OB$$

$$PB_{conc} = TL2_{conc} * FCM\ 3/2 * FCM\ PB$$

$$0.195\ mg/kg = (0.58 * 5.7 * TL2_{conc}) + (0.13 * 5.7 * 3.0 * TL2_{conc}) + (0.13 * 10 * TL2_{conc}) + (0.05 * 5.7 * 12.5 * TL2_{conc})$$

Solving for $TL2_{conc}$:

$$TL2_{conc} = 0.019 \text{ mg MeHg/kg fish} \quad \textit{(not eaten by eagles; used to determine other safe levels)}$$

$$TL3_{conc\ large\ fish} = 0.019 * 5.7 = 0.11 \text{ mg MeHg/kg fish}$$

$$TL4_{conc\ large\ fish} = 0.019 * 5.7 * 3.0 = 0.31 \text{ mg MeHg/kg fish}$$

$$OB_{conc} = 0.019 * 10 = 0.19 \text{ mg MeHg/kg omnivorous birds}$$

$$PB_{conc} = 0.019 * 5.7 * 12.5 = 1.35 \text{ mg MeHg/kg piscivorous birds}$$

4.5.3.4 Peregrine Falcon Safe Tissue Levels

Peregrine falcons consume almost exclusively avian prey, some of which is aquatic-dependent. To solve for safe concentrations in omnivorous and piscivorous bird prey, these terms are expressed as functions of the lowest trophic level common to the birds' food web, which is TL2 aquatic prey (USFWS, 2004).

$$TDSL_{peregrine} = (\%diet_{OB} * OB_{conc}) + (\%diet_{PB} * PB_{conc})$$

Where: $OB_{conc} = TL2_{conc} * \text{FCM OB}$

$$PB_{conc} = TL2_{conc} * \text{FCM 3/2} * \text{FCM PB}$$

$$0.139 \text{ mg/kg} = (0.10 * 10 * TL2_{conc}) + (0.05 * 5.7 * 12.5 * TL2_{conc})$$

Solving for $TL2_{conc}$:

$$TL2_{conc} = 0.030 \text{ mg MeHg/kg fish} \quad \textit{(not eaten by peregrines; used to determine other safe levels)}$$

$$OB_{conc} = 0.030 * 10 = 0.30 \text{ mg MeHg/kg omnivorous birds}$$

$$PB_{conc} = 0.030 * 5.7 * 12.5 = 2.2 \text{ mg MeHg/kg piscivorous birds}$$

Note that the safe fish tissue levels in Table 4.3 are partially watershed-dependent and are specific to the Delta. The acceptable, average fish tissue concentrations for wildlife consuming from one trophic level will be consistent across different water bodies. This is because all of the parameters used to calculate the safe fish levels (species body weight, consumption rate and reference dose) were obtained from published literature and apply on a national or regional scale (Table 4.2). For species consuming fish from two trophic level classifications or piscivorous birds, translators (FCM or TLR) were used to calculate the safe concentrations in prey fish and piscivorous birds. These translators should be derived from site-specific data when possible and may differ between watersheds. For the Delta targets, the TLR and FCM between trophic level 4 and 3 fish were specific to the Delta. The FCMs for piscivorous birds, omnivorous birds and trophic level 3 fish were literature-derived average values.

Central Valley Water Board staff is not proposing safe tissue levels in piscivorous or omnivorous birds as TMDL targets. Data are lacking to compare safe levels in bird prey with existing conditions. By lowering methylmercury concentrations in fish and aquatic prey to safe levels shown in Table 4.3, staff anticipates that concentrations in birds feeding in the aquatic food web will decline to safe levels as well. In particular for peregrine falcon, the desired safe level in piscivorous birds is 2.2 mg/kg. Dividing the safe piscivorous bird level by 12.5 (FCM PB) results in a safe level in TL3 prey fish (150-350 mm length) of 0.17 mg/kg, which is above the proposed target for large TL3 fish.

Wildlife targets for TL3 and TL4 fish greater than 150 mm in length may be directly compared with targets developed to protect human consumers, as discussed in the following section. In Section 4.7, the wildlife and human targets that are trophic level and size-specific are incorporated into a single target based on largemouth bass that is protective of humans and all wildlife species of concern.

4.6 Human Health Targets

Numeric targets can be developed to protect humans in a manner analogous to targets for wildlife. A reference dose, average body weight and consumption rates are used along with Equations 4.1 and 4.3 to calculate safe fish tissue levels. In this section, the human health exposure parameters are discussed.

4.6.1 Acceptable Daily Intake Level

Central Valley Water Board staff used the USEPA RfD for methylmercury (USEPA, 2001) in Delta target calculations. The adverse effect level is based upon results of tests of neuropsychological function in children in the Faroe Islands exposed to methylmercury in fish. The USEPA incorporated a composite uncertainty factor of 10 for a final RfD of 0.1 µg methylmercury/kg bwt/day (USEPA, 2001). The USEPA describes its RfD as an estimate of a daily exposure level to humans that is likely to be without an appreciable risk of deleterious effect during a lifetime. The USEPA RfD is applied to the general population.[16]

4.6.2 Body Weight & Consumption Rate

This report uses the USEPA's standard adult bodyweight of 70 kg. Using an average pregnant female bodyweight (65 or 67 kg) would have very little difference on the calculation of mercury targets in fish.

Consumption rate is the most difficult of the fish tissue target variables to define because human consumption patterns are variable. The amount of methylmercury ingested is highly dependent on the amount of fish and the sizes and species of fish consumed. The desired level of fishing and consuming from the Delta lies somewhere between the limited amount recommended in the existing fish advisory and a probable upper bound of a very high consumer (i.e., the 99th percentile in United States consumption studies). People could eat unlimited quantities of fish from the Delta only if the fish mercury concentration was reduced to zero. Beneficial use protection in the case of mercury pollution, therefore, must be accomplished by a combination of cleanup and education. Education is a needed part of a TMDL implementation plan until effects of all mercury reduction efforts are reflected in fish tissue levels. During the implementation period, education is needed to encourage consumers to eat smaller fish and species with lower mercury concentrations.

[16] "In the studies so far published on subtle neuropsychological effects in children, there has been no definitive separation of prenatal and postnatal exposure that would permit dose-response modeling. That is, there are currently no data that would support the derivation of a child (versus general population) RfD. This RfD is applicable to the lifetime daily exposure for all populations, including sensitive subgroups. It is not a developmental RfD per se, and its use is not restricted to pregnancy or developmental periods" *Water Quality Criterion for Methylmercury, Section 4-6* (USEPA 2001).

The California Department of Health Services has interviewed members of sub-populations thought to have high consumption rates (CDHS, 2004). However, a comprehensive survey of consumption of fish from the Delta has not been conducted. The USEPA recommends default consumption rates for the general population and various subpopulations (USEPA, 2001). Default consumption rates are derived from data collected nationwide as part of the 1994-96 USDA Continuing Survey of Food Intake by Individuals (CFSII). The USEPA reports rates separately for consumption of freshwater and marine fish. The USEPA recommends a default fish intake rate of 17.5 g/day (about one 8-ounce meal every two weeks[17]) to adequately protect the general population consuming freshwater and estuarine fish. This value represents the 90th percentile consumption rate for all survey participants, including those who do not eat fish. In selecting the 90th percentile, rather than the mean or median, the USEPA intended to recommend a consumption rate that is protective of the majority of the entire population. The USEPA recommended a consumption rate of 142.4 g/day (four to five fish meals per week) of local fish for the development of a human health criterion for anglers whose main source of protein is from locally caught fish. This value represents the 99th percentile consumption rate for all survey participants.

A detailed survey of consumption by anglers in San Francisco Bay was conducted in 1998 and 1999 (SFEI, 2000). The consumption rates for the 90th and 95th percentiles of anglers that were "consumers" (consumed Bay fish at least once prior to the interview) were 16 and 32 g/day, respectively. The San Francisco Bay Mercury TMDL selected the consumption rate for the 95th percentile of anglers (32 g/day) for calculation of the San Francisco Bay fish mercury target (0.2 mg/kg) to protect people who choose to eat San Francisco Bay fish on a regular basis (Johnson & Looker, 2004).

4.6.3 Consumption of Fish from Various Trophic Levels & Sources

Species and size of fish as well as consumption rate affect methylmercury intake. It is difficult to estimate amounts of various species of sport fish that might be consumed from the Delta. Based on the CSFII national survey, the USEPA assumed that on average, humans eat freshwater and estuarine fish from trophic levels two (3.8 g/day), three (8.0 g/day) and four (5.7 g/day) (USEPA, 2001). These rates are 21.7, 45.7, and 32.6% of the total 17.5 g/day, respectively. Trophic level 2 species, such as clams, shrimp and shimofuri goby, are harvested from the Delta for human consumption (Appendix C). However, CDFG creel surveys (CDFG, 2000-2001) and anecdotal information provided by CDFG staff (Schroyer, 2003) indicate that many Delta anglers are unlikely to take home TL2 species. As described in Figure C.1 in Appendix C, the creel surveys indicate that Delta anglers may target an almost even mix of TL3 (American shad, salmon, sunfish, splittail) and TL4 (catfish and striped bass) fish in the Sacramento and Mokelumne Rivers subareas of the Delta, and primarily TL4 species (striped bass and catfish) throughout the rest of the Delta. However, anecdotal information provided by CDFG staff (Schroyer, 2003) indicates that many Delta anglers take home a mix of TL3 and TL4 fish species.

Many fish consumers eat a combination of locally caught and commercially bought fish. When determining safe levels of consumption of Delta fish, the intake of methylmercury from commercial fish should be taken into account (see definition of RSC in Section 4.4). Based on the national CFSII survey, the USEPA assumes an average consumption rate of commercial fish of 12.46 g/day, which results in an

[17] Although the target calculations use bodyweights and consumption rates for adult humans, the resulting fish tissue levels protect children as well. Children's bodyweights and smaller portion sizes can also be fitted into Equations 4.1 and 4.3. The OEHHA has published a table of sizes of typical meals of fish that correspond to smaller bodyweights (OEHHA, 1999). Children would only be at risk of mercury toxicity if they consumed more than the average portion for their body size.

average daily intake of 0.027 µg methylmercury/kg bwt-day (USEPA, 2001). For people eating fish from commercial markets and the Delta, the safe intake level of methylmercury from Delta fish is the reference dose minus the methylmercury from commercial fish (0.1 µg/kg-day minus 0.027 µg/kg-day equals 0.073 µg/kg-day).[18]

4.6.4 Safe Rates of Consumption of Delta Fish

The USEPA issued a recommended methylmercury criterion of 0.3 mg/kg (rounded from 0.29 mg/kg[19]) in fish consumed by humans (USEPA, 2001). The USEPA human health criterion was calculated using a default consumption rate of freshwater/estuarine fish of 17.5 g/day (about one meal every two weeks) and commercial (marine) fish of 12.46 g/day, as derived from national dietary surveys described above (USEPA, 2001). The criterion assumed that on average, humans eat freshwater and estuarine fish from TL2 (21.7%), TL3 (45.7%) and TL4 (32.6%). However, the 2001 Water Quality Criterion report noted that the criterion can be adjusted on a site-specific or regional basis to reflect regional or local conditions and/or specific populations of concern. These include the consumption rates of local fish and the RSC estimate. The report also noted that States also can choose to apportion an intake rate to the highest trophic level consumed for their population or modify EPA's default intake rate based on local or regional consumption patterns. For example, the San Francisco Bay mercury target of 0.2 mg/kg was calculated using a consumption rate of 32 g/day (about one meal per week) derived from a San Francisco Bay consumption survey. The San Francisco Bay mercury target was applied to a single TL4 species, striped bass, because Bay-area consumers favor striped bass and striped bass contain relatively high mercury concentrations (Johnson & Looker, 2004; SFEI, 2000).

In the absence of Delta-specific consumption rates, the USEPA default consumption rate (17.5 g/day), San Francisco Bay consumption rate (32 g/day), and USEPA recommended consumption rate for anglers whose main source of protein is from locally caught fish (142.4 g/day) were used in Equation 4.1 to estimate the safe methylmercury level in the total diet for humans consuming Delta fish (Table 4.5). In addition, scenarios were developed for anglers that consume Delta and commercial fish, and for anglers that consume only Delta fish. For each of the total diet safe levels associated with the different consumption rates, three different distributions of locally caught fish were considered.

Equation 4.3 was used to develop safe levels for each trophic level of Delta fish. In order to solve Equation 4.3 for the desired concentrations in TL2, TL3 and TL4 biota, concentrations in the higher trophic levels are put in terms of the concentration in the lowest trophic level. Equation 4.3 is then rearranged to solve for the lowest trophic level concentration. In order to express the concentration in a higher trophic level, trophic level ratios were used. The TLRs used in the calculation of Delta human targets are shown in Table 4.6. Existing Delta fish concentration data were used to develop the ratios. The following example illustrates how the trophic level fish targets were developed for Scenario A.1 in Table 4.5 using Equations 4.1 and 4.3.

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[18] Most commercial fish do not come from the Delta. The most popular fish and seafood bought in commercial markets are marine species such as scallops, shrimp, and tuna. The average consumption rate of marine fish reported by all respondents in the national CFSII survey was 12.46 g/day (three meals every two months; USEPA, 2001). The average concentration of methylmercury in commercial species weighted by frequency of consumption is 0.16 mg/kg (USEPA, 2001; see also www.cfsan.fda.gov/seafood1.html.)

[19] The USEPA rounded from 0.288 mg/kg to 0.3 mg/kg for use as its recommended methylmercury criterion. Central Valley Water Board staff's calculations throughout the rest of this report are rounded to two decimal places, e.g., 0.29 mg/kg.

Per Equation 4.1:

$$\text{Safe MeHg in total diet of Delta fish} = \frac{\text{(Human RfD - Relative source contribution) * Body weight}}{\text{Consumption rate}}$$

$$0.29\ \text{mg/kg} = \frac{0.073\ \mu\text{g MeHg/kg-day} * 70\ \text{kg}}{17.5\ \text{g/day}}$$

Per Equation 4.3:

$$0.29\ \text{mg/kg} = (\%\ \text{dietTL}_2 * \text{TL3}_{conc}) + (\%\ \text{dietTL}_3 * \text{TL3}_{conc}) + (\%\ \text{dietTL}_4 * \text{TL4}_{conc})$$

Where: $\text{TL3}_{conc} = \text{TL2}_{conc} * \text{TLR 3/2}$

$\text{TL4}_{conc} = \text{TL2}_{conc} * \text{TLR 3/2} * \text{TLR 4/3}$

$$0.29\ \text{mg/kg} = (21\% * \text{TL2}_{conc}) + (46\% * \text{TL2}_{conc} * 4.5) + (33\% * \text{TL2}_{conc} * 4.5 * 2.9)$$

Solving for TL2_{conc}:

TL2_{conc} = 0.30 / (0.21 + (0.45*4.5) +(0.33*4.5*2.9)) = 0.046 mg/kg in shrimp & clams

TL3_{conc} = 0.046 mg/kg * 4.5 = 0.20 mg/kg in 150-500 mm fish

TL4_{conc} = 0.046 mg/kg * 4.5 * 2.9 = 0.45 mg/kg in 150-500 mm fish

As indicated by Table 4.5, potential safe levels of mercury in large Delta TL4 fish range from 0.05 to 0.80 mg/kg, depending on the assumed trophic level distribution of locally caught fish and the amount of Delta and commercial fish consumed. The highlighted safe levels for TL3 and TL4 fish developed by Scenarios A.1, A.3, B.2 and E.3 are evaluated as water quality objective alternatives in Chapter 3 of the Proposed Basin Plan Amendment draft staff report. The TL3 and TL4 targets produced by Scenario B.2 of 0.08 mg/kg and 0.24 mg/kg, respectively, are recommended by Central Valley Water Board staff for the protection of humans who consume fish from throughout the Delta because they are protective of a higher consumption rate than that used to develop the USEPA criterion and because available information indicates that anglers take home a mixture of TL3 and TL4 species. These targets are carried forward throughout the rest of this report for use in the food web evaluation, linkage analysis and development of methylmercury source allocations. Central Valley Water Board staff will update the calculations presented in Table 4.5 as Delta-specific consumption information becomes available.

Table 4.5: Safe Concentrations of Methylmercury in Delta Fish by Trophic Level (TL) to Protect Humans Calculated Using Varying Assumptions about Consumption Rates and Trophic Level Distribution

Scenario	Body Weight (kg)	Acceptable Daily Delta Fish MeHg Intake Level (µg/kg-day) (a)	Total Consumption Rate of Delta Fish (g/day) (b)	Safe MeHg Level in Total Diet of Delta Fish (mg/kg) (c)	Distribution of Locally Caught Fish by TL			Safe Concentration of MeHg in Fish by TL (mg/kg) (d)		
					TL2	TL3	TL4	TL2	TL3	TL4
For people eating commercial and Delta fish:										
A.1	70	0.073	17.5	0.29	21.7%	45.7%	32.6%	0.04	**0.20**	**0.58**
A.2					---	50%	50%		0.15	0.43
A.3					---	---	100%			**0.29**
B.1	70	0.073	32	0.16	21.7%	45.7%	32.6%	0.02	0.11	0.32
B.2					---	50%	50%		**0.08**	**0.24**
B.3					---	---	100%			0.16
For people eating only Delta fish:										
C.1	70	0.1	17.5	0.40	21.7%	45.7%	32.6%	0.06	0.28	0.80
C.2					---	50%	50%		0.21	0.59
C.3					---	---	100%			0.40
D.1	70	0.1	32	0.22	21.7%	45.7%	32.6%	0.03	0.15	0.44
D.2					---	50%	50%		0.11	0.33
D.3					---	---	100%			0.22
E.1	70	0.1	142.4	0.05	21.7%	45.7%	32.6%	0.01	0.03	0.10
E.2					---	50%	50%		0.03	0.07
E.3					---	---	100%			**0.05**

(a) For people eating fish from commercial markets and the Delta, the safe intake level of methylmercury from Delta fish is the USEPA reference dose minus the methylmercury from commercial fish (0.1 µg/kg-day minus 0.027 ug/kg-day = 0.073 ug/kg-day). Scenarios C through E assume no commercial fish are consumed.

(b) The USEPA human health criterion was calculated using a default consumption rate of freshwater/estuarine fish of 17.5 g/day and of commercial (marine) fish of 12.46 g/day, as derived from national dietary surveys (USEPA, 2001). The criterion assumed that on average, humans eat freshwater and estuarine fish from TL2 (21.7%), TL3 (45.7%) and TL4 (32.6%).

(c) The USEPA criterion calculations yielded a methylmercury value of 0.288 mg methylmercury/kg fish, which the USEPA rounded to one significant digit. The Region 2 San Francisco Bay Mercury TMDL target calculations yielded a methylmercury value of 0.16 mg methylmercury/kg fish, which Region 2 also rounded to one significant digit in the San Francisco Bay Mercury TMDL report (Johnson & Looker, 2004).

(d) Values were calculated using Equation 4.3 and trophic level ratios presented in Table 4.6. Values were rounded to two decimal places. The highlighted targets (Scenarios A.1, A.3, B.2 and E.3) are evaluated as water quality objective alternatives in the Proposed Basin Plan Amendment draft staff report. The TL3 and TL4 targets produced by Scenario B.2 are recommended for the protection of humans that consume fish from throughout the Delta and are carried forward throughout the rest of this report for use in the linkage analysis and development of allocations.

Table 4.6: Trophic Level Ratios for Delta Human Target Development

Translator	Value	Source
TLR 4/3	2.9	Ratio between existing MeHg concentrations in large TL4 fish (150 mm [or legal catch limit] to 500 mm length) and large TL3 fish (150 mm [or legal catch limit] to 500 mm length). Calculated from Delta-wide average fish tissue levels; see Appendix B.
TLR 3/2	4.5	Ratio between existing MeHg concentrations in large TL3 fish (150-500 mm length) and TL2 species potentially consumed by humans (shrimp and clams). Calculated from Delta-wide average fish tissue levels; see Appendices B, C and L.

4.7 Trophic Level Food Group Evaluation

As noted in the previous section, Central Valley Water Board staff recommends targets of 0.08 and 0.24 mg/kg in large TL3 and TL4 fish, respectively, for the protection of humans that consume fish from throughout the Delta. In this section, the relationships between methylmercury concentrations in large TL4 fish and the other trophic level food groups are examined. The purpose of this analysis is to determine whether consistent relationships might exist between the assemblages of fish and, if so, whether it might be possible to describe safe mercury ingestion rates for humans and wildlife species in terms of large TL4 fish. This analysis enables staff to determine whether a water quality objective based on methylmercury in large fish developed for the protection of humans may or may not be protective of wildlife species that consume smaller or lower trophic level fish.

4.7.1 Data Used in Trophic Level Food Group Evaluation

Mercury concentrations for each trophic level food group sampled in the Delta are summarized in Table 4.7. Values presented are average concentrations, weighted by the number of individual fish in composite samples. The trophic level food group concentrations are the result of analyzing 1,048 composite samples of 4,578 fish from 23 species in the Delta (Table B.2 and B.3 in Appendix B). Figure 4.1 illustrates the fish sampling locations used in the trophic level food group evaluation. The sampling was conducted by CDFG, SFEI, University of California, Davis, the Toxic Substances Monitoring Program, and the Sacramento River Watershed Program (Davis *et al.*, 2000; Davis *et al.*, 2003; Slotton *et al.*, 2003; LWA, 2003; SWRCB-DWQ, 2002).

The data for each food group were assembled after considering four general rules. First, the data were restricted to samples collected between 1998 and 2001, the period with the most comprehensive sampling across the Delta. Second, migratory species (salmon, American shad, steelhead, sturgeon, striped bass) were excluded. These species likely do not reside year-round at the locations in the Delta where they were caught and their tissue mercury levels may not show a positive relationship with the mercury levels in resident animals. In addition, data for migratory species are not available for all Delta subareas, precluding an analysis to determine whether such a relationship might exist. A review of data available for several commercial species (striped bass, salmon, blackfish and crayfish) is provided in Appendix C.[20]

[20] Methylmercury concentrations in salmon and striped bass are important to human risk assessment because people frequently attempt to catch these two species. Average mercury concentrations in striped bass are similar to mercury levels in largemouth bass. The available mercury data for salmon indicate that their tissue concentrations are much lower that the mercury levels in bass (0.04 to 0.12 mg/kg). See Appendix C for more information about striped bass and salmon.

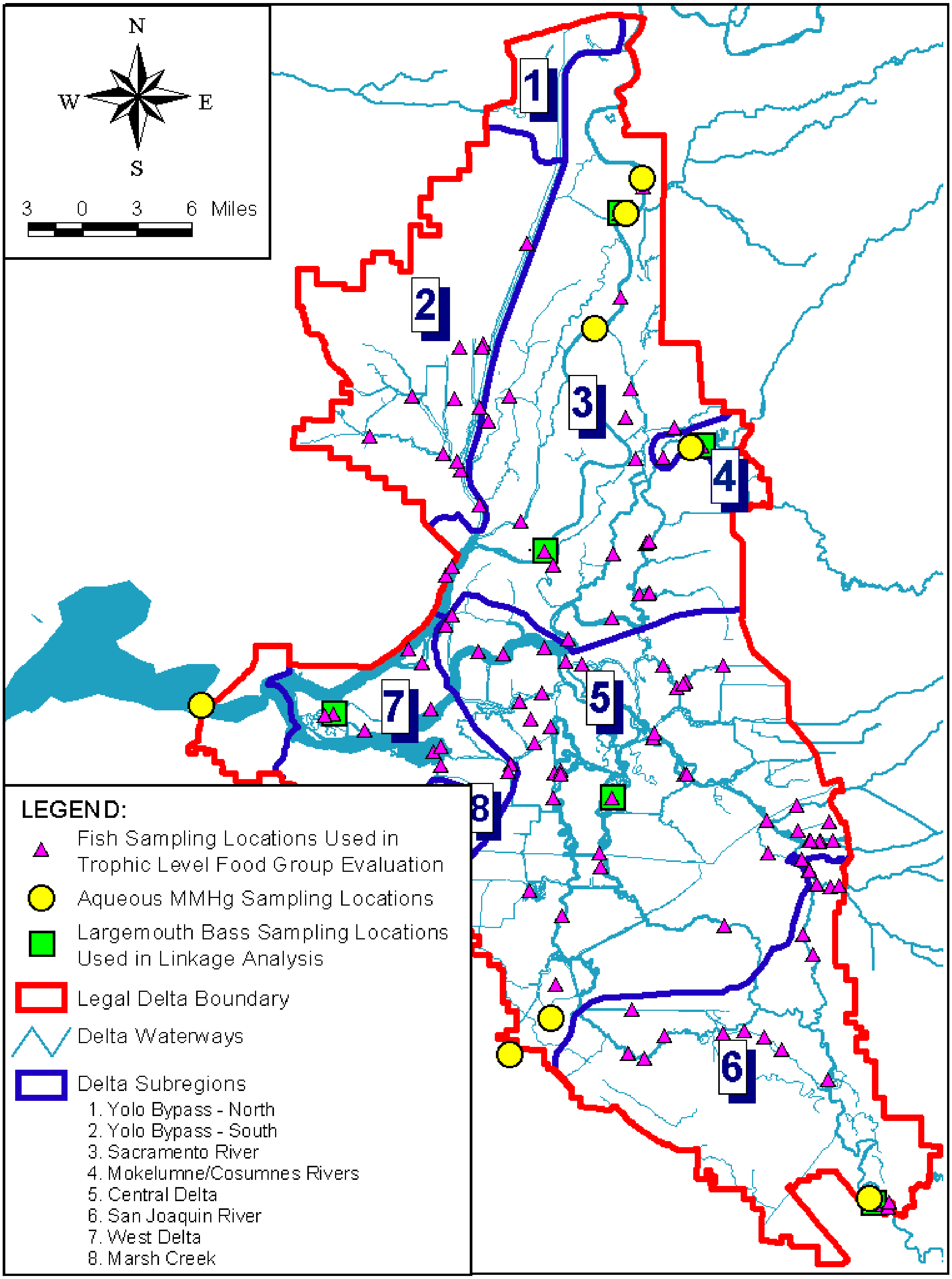

Figure 4.1: Fish & Water Sampling Locations Included in the Trophic Level Food Group and Largemouth Bass Evaluations.

Table 4.7: Mercury Concentrations in Trophic Level Food Groups Sampled in the Delta

Trophic Level Food Group	Hg Concentrations (mg/kg) by Delta Subarea (a)				
	Central Delta	Mokelumne River	Sacramento River	San Joaquin River	West Delta
TL4 Fish (150-500 mm)	0.26	0.92	0.56	0.50	0.32
TL3 Fish (150-500 mm)	0.08	0.28	0.21	0.11	0.11
TL4 Fish (150-350 mm)	0.20	0.75	0.46	0.42	0.24
TL3 Fish (150-350 mm)	0.08	0.29	0.17	0.12	0.08
TL3 Fish (50-150 mm)	0.03	0.09	0.04	0.04	0.03
TL3 Fish (<50 mm)	0.02	0.07	0.03	0.04	0.03

(a) The trophic level food group mercury levels are weighted averages of mercury levels for resident fish within each food group collected in each Delta subarea between 1998 and 2001. These food groups correspond to the proposed numeric targets developed earlier in Chapter 4. Weighted average mercury concentration is based on the number of fish in the composite samples analyzed, rather than the number of samples.

Third, fish samples with lengths greater than 500 mm were not included. Data for fish larger than 500 mm are available for only some subareas. Capping the size at 500 mm allows comparable data for all Delta subareas. Finally, only fish fillet data were used in the human and eagle trophic level food group analysis. Humans typically consume fish fillets, while wildlife species, including eagles, eat whole fish. However, all the data for large fish typically consumed by eagles and other large wildlife species are from fillet samples, making it necessary to use fillet information for these species.[21] Whole fish data were used for the smaller wildlife species food groups.

Of the eight Delta subareas identified in Section 2.2.2 and Figure 2.2, three of the subareas were not included in the trophic level food group evaluation due to inadequate information. No fish were sampled from the Marsh Creek subarea between 1998 and 2001. In addition, small fish were sampled throughout the Yolo Bypass-South subarea between 1998 and 2001, but large fish were sampled only in the southernmost area; hence, the mercury levels in the trophic level food groups are not geospatially comparable. The only fish sampling conducted in the Yolo Bypass-North subarea took place in Greens Lake, which is not considered representative of the entire subarea. In addition, only large TL4 fish were sampled; no small fish were sampled.

Table 4.8 provides a comparison of the average mercury concentrations for each trophic level food group sampled in the Delta (Table 4.7) to the recommended targets for the species with the lowest safe fish methylmercury levels within each trophic level food group. The comparison indicates that the recommended targets for wildlife protection are already met in the Central and West Delta subareas. In addition, the comparison indicates that greater reductions may be required to achieve the recommended target for large TL4 fish developed for human protection than for the recommended targets for smaller

[21] Researchers in New York found that concentrations in whole body and muscle of large TL3 and TL4 fish were not significantly different (Becker and Bigham, 1995), suggesting that it is appropriate to use fillet data to evaluate exposure to wildlife species.

and lower trophic level fish developed for wildlife protection. The following section describes a more direct method for comparing the level of protection provided by the different trophic level food group targets.

Table 4.8: Percent Reductions in Fish Methylmercury Levels Needed to Meet Numeric Targets

Trophic Level Food Group	Target Species (a)	Target (mg/kg)	Delta Subareas				
			Central Delta	Mokelumne River	Sacramento River	San Joaquin River	West Delta
TL4 Fish (150-500 mm)	Human	0.24	8%	74%	57%	52%	25%
TL3 Fish (150-500 mm)	Human	0.08	0%	71%	62%	27%	27%
TL4 Fish (150-350 mm)	Osprey	0.26	0%	65%	43%	38%	0%
TL3 Fish (150-350 mm)	Grebe	0.08	0%	72%	53%	33%	0%
TL3 Fish (50-150 mm)	Kingfisher	0.05	0%	44%	0%	0%	0%
TL3 Fish (<50 mm)	Least Tern	0.03	0%	57%	0%	25%	0%

(a) Only the recommended targets for the wildlife species with the lowest safe methylmercury concentrations in fish diet (Table 4.3) within each trophic level food group are evaluated. The proposed large TL3 and TL4 fish targets for human protection are lower than the targets proposed for protection of eagles.

4.7.2 Trophic Level Food Group Comparisons

Regressions between methylmercury concentrations in large TL4 fish and the other TL food groups are presented in Figure 4.2. The relationships were evaluated using linear, exponential, logarithmic and power curves; in each case the type of curve that provided the highest R^2 value was selected. All of the correlations were statistically significant ($P<0.05$ or less). The regressions demonstrate that there are predictable relationships between mercury concentrations in large TL4 fish and the other trophic level food groups in the Delta.

Table 4.9 presents the predicted safe dietary mercury concentrations for each target species in terms of large TL4 fish calculated from the regression equations in Figure 4.2. The target of 0.24 mg/kg in large TL4 fish developed for the protection of humans is lower than the corresponding safe large TL4 fish mercury concentrations predicted for the other TL food groups, which ranged from 0.30 mg/kg for Western grebe to 1.12 mg/kg for Western snowy plover. This indicates that the large TL3 and TL4 fish targets developed for protection of humans are most likely protective of wildlife species that consume smaller or lower trophic level fish. In other words, reductions in methylmercury levels needed to achieve the target for large TL3 and TL4 fish are expected to produce reductions in smaller fish sufficient to fully protect wildlife species. To ensure that wildlife species dining only on small fish are protected, staff proposes an additional target of 0.03 mg/kg methylmercury in TL2 and 3 fish less than 50 mm in length. This target represents the safe level for prey consumed by the California least tern, a piscivorous species listed by the federal government as endangered. As shown in Table 4.9, such a target for small fish also would protect the Western snowy plover.

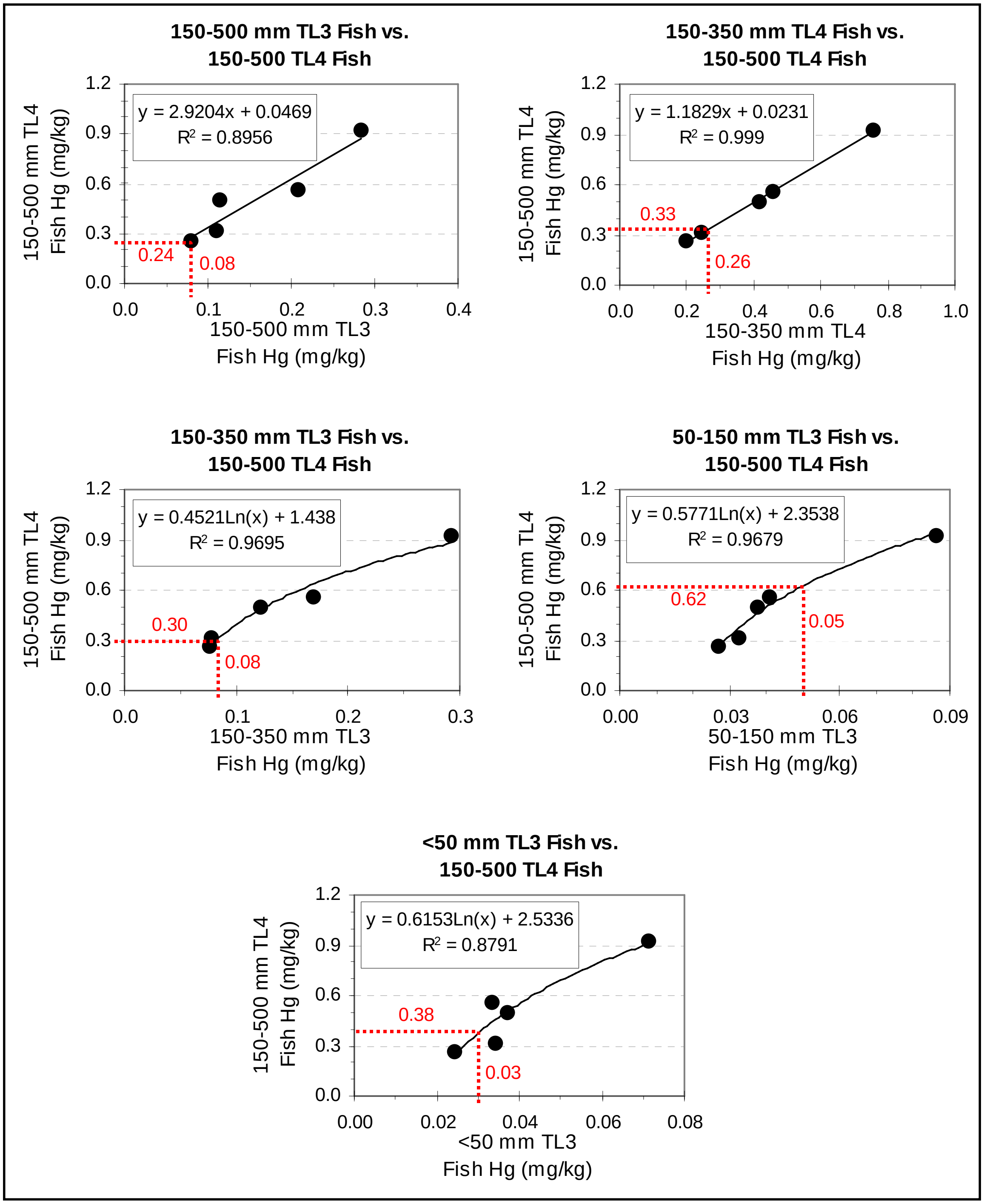

Figure 4.2: Comparison of Methylmercury Concentrations in Large (150-500 mm) TL4 Fish and Other Trophic Level (TL) Food Groups. The regressions are used to predict safe diets for target species listed in Table 4.9 in terms of large TL4 fish.

Table 4.9: Predicted Safe Concentrations of Methylmercury in 150-500 mm TL4 Fish and Standard 350-mm Largemouth Bass Corresponding to Trophic Level Food Group (TLFG) Targets for the Protection of Piscivorous Species.

Trophic Level Food Group / Species	**TLFG Target** (mg/kg) (a)	**Predicted 150-500 mm TL4 Fish Safe Level** (mg/kg)	**Predicted Standard 350-mm Largemouth Bass Safe Level** (mg/kg) (b)
TL4 Fish (150-500 mm)			
Human	0.24	(c)	0.28
Bald eagle	0.31	(c)	0.36
TL3 Fish (150-500 mm)			
Human	0.08	0.24	0.24
Bald eagle	0.11	0.37	0.43
TL4 Fish (150-350 mm)			
Osprey	0.26	0.33	0.36
River otter	0.36	0.45	0.57
TL3 Fish (150-350 mm)			
Western grebe	0.08	0.30	0.31
Common merganser	0.09	0.35	0.38
Osprey	0.09	0.35	0.38
TL3 Fish (50-150 mm)			
Kingfisher	0.05	0.62	0.73
Mink	0.08	0.90	1.06
River otter	0.04	0.50	0.57
Double-crested cormorant	0.09	0.96	1.15
TL3 (<50 mm)			
California least tern	0.03	0.38	0.42
Western snowy plover	0.10	1.12	1.34

(a) The TLFG targets developed for bald eagle, osprey and river otter were developed using site-specific TLRs and/or FCMs combined with information provided in published literature. All other TLFG targets were entirely developed using information provided in published literature.
(b) The calculation and purpose of the standard 350-mm largemouth bass mercury concentrations are described in the following section (Section 4.8).
(c) The TL4 Goals are same as the TLFG Targets for human and eagle protection.

4.8 Largemouth Bass Evaluation

A goal of the TMDL is to link target methylmercury concentrations in fish to methylmercury concentrations in water to develop a goal for aqueous methylmercury that could then be used in development of an implementation plan. Chapter 5 (Linkage Analysis) describes the relationships between methylmercury in water and in largemouth bass in the Delta. Largemouth bass were selected for the linkage analysis for several reasons. Largemouth bass are a good bioindicator species. In addition, only largemouth bass data are available for the same sampling period and locations as the methylmercury water data (Figure 4.1). Largemouth bass, however, constitute only a portion of the diet of some of the human and wildlife consumers of Delta fish. The methylmercury targets determined above assume that humans and wildlife species consume a variety of sizes and species of fish from the Delta. In this section, the relationships between methylmercury concentrations in largemouth bass and the trophic level food groups were examined so that an implementation goal could be developed in terms of largemouth bass and, ultimately, linked to aqueous methylmercury.

Most of the information on mercury concentrations in the various trophic level food groups in the Delta was collected as species-specific composite samples between 1998 and 2001. Therefore, the largemouth bass evaluation was conducted in four parts. First, the methylmercury concentrations in largemouth bass of a standard size were estimated for each Delta subarea using the relationships between length and methylmercury tissue concentration[22] in samples collected in 2000. Second, correlations were run between standard 350-mm largemouth bass collected in 2000 and average concentrations of 300-400 mm largemouth bass (composite and individual samples) collected between 1998 and 2000. The year 2000 is significant because (1) aqueous methylmercury sampling began in March 2000 and (2) largemouth bass sampling adequate for the length/concentration regressions took place only in September/October 2000. The monthly March-October 2000 subset of the aqueous data has the greatest overlap with the lifespan of the largemouth bass sampled in September/October 2000. As these correlations were highly significant, the third step was to examine correlations between mercury concentrations in standard 350-mm largemouth bass and composites of all trophic level food groups collected in the Delta between 1998 and 2001. The purpose of this analysis was to determine whether consistent relationships might exist between the different assemblages of fish and, if so, whether it might be possible to describe safe mercury ingestion rates for humans and wildlife species in terms of the methylmercury concentration in a standard 350-mm largemouth bass. The final step was to determine a safe methylmercury concentration for each species in terms of the methylmercury concentration in 350-mm largemouth bass (Table 4.9).

4.8.1 Largemouth Bass Standardization

The methylmercury content of a standard 350-mm length largemouth bass was determined at all sites where both water and fish tissue data were available (Figure 4.1) by regressing fish length against mercury body burden (Figure 4.3). Table 4.10 presents the predicted mercury values for 350 mm bass at each location. The predicted mercury concentration in standard 350 mm largemouth bass varied by a factor of five across the Delta (0.19 mg/kg in the Central Delta to 1.04 mg/kg in the Mokelumne River). Mercury concentration in a standard length 350 mm largemouth bass was selected because the length is near the middle of the size range collected at each site and therefore maximizes the predictive capability of the regression (Davis and Greenfield, 2002). Three hundred and fifty mm is slightly larger than CDFG's legal size limit of 305 mm (12 inches). A 350 mm bass is three to five years old (Shaffter, 1998; Moyle, 2002).

[22] Determining the methylmercury concentration in a specific or "standard" size fish is a typical method of data analysis that allows comparison between sites and years. For largemouth bass from one site or subarea, mercury concentration is well correlated with length (Davis & Greenfield, 2002; data in Figure 4.2). This correlation is also useful in monitoring, as concentrations in fish in a range of lengths can be used to predict the concentration in a standard size. Hereafter, the mercury concentration in a "standard 350 mm largemouth bass" refers to the concentration obtained through a regression analysis as in Figure 4.2.

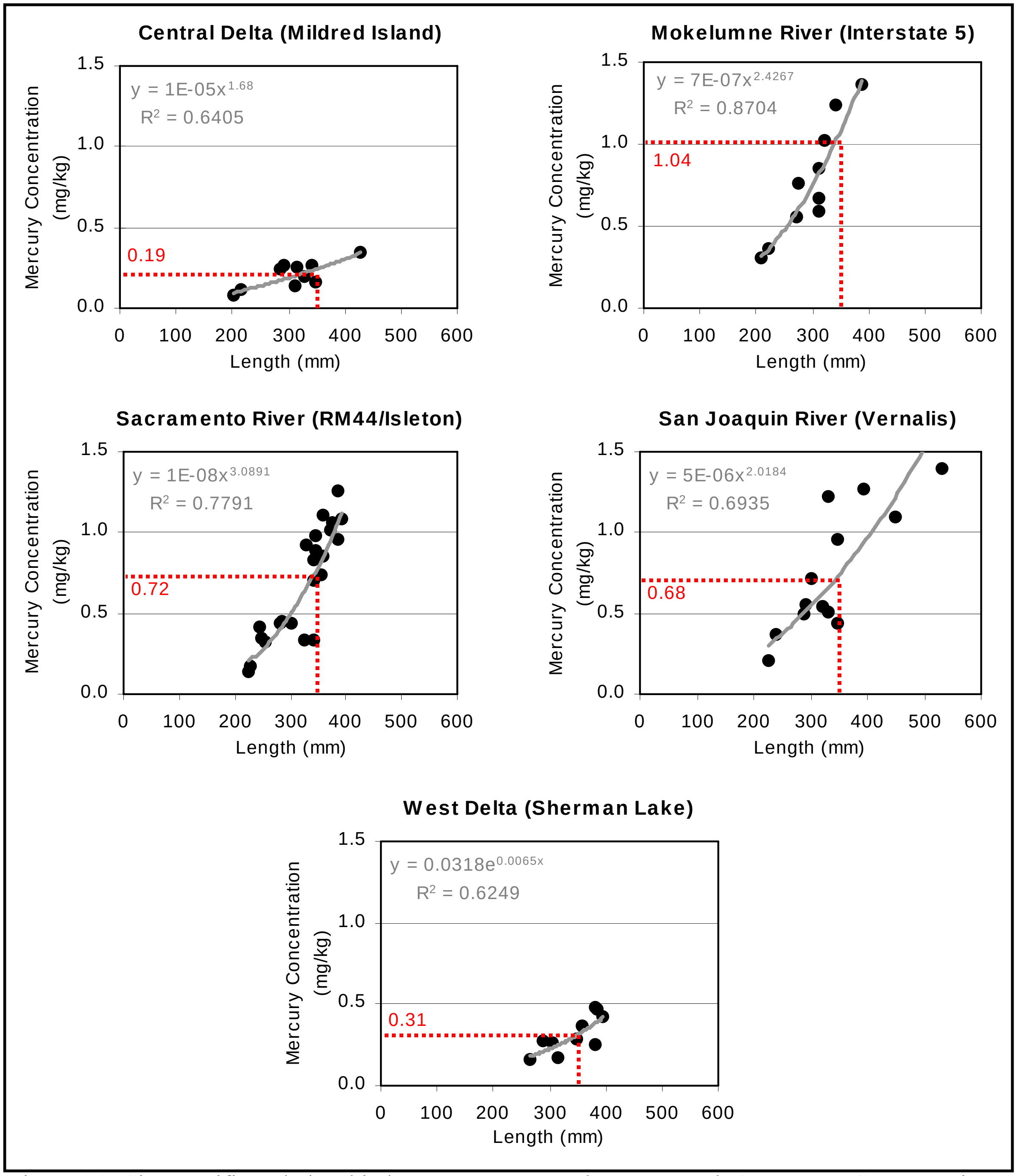

Figure 4.3: Site-specific Relationship between Largemouth Bass Length & Mercury Concentrations in the Delta. The relationships were used to predict the mercury content of a standard, 350-mm length bass sampled in September/October 2000, as indicated by the dashed lines. All relationships were significant at least at $P<0.05$.

4.8.2 Correlations between Standard 350 mm and All Largemouth Bass Data

Figure 4.4 presents the regression between mercury levels in standard 350-mm largemouth bass collected in year 2000 and weighted-average concentrations in 300-400 mm largemouth bass collected between 1998 and 2000 in five delta subareas[23] (Table 4.10). Each data point represents one subarea. The correlation is statistically significant ($P<0.01$) and has a slope of 0.8, suggesting that mercury concentrations do not vary appreciably between the two groups. The results suggest that year 2000 standard 350-mm bass mercury levels are representative of mercury concentrations in largemouth bass collected between 1998 and 2000.

Table 4.10: Mercury Concentrations in Standard 350-mm & 300-400 mm Largemouth Bass

	Hg Concentrations (mg/kg) by Delta Subarea				
	Central Delta	Mokelumne River	Sacramento River	San Joaquin River	West Delta
Year 2000 Standard 350-mm largemouth bass collected in September/October 2000 (a)	0.19	1.04	0.72	0.68	0.31
300-400 mm largemouth bass collected between 1998 and 2000 (b)	0.31	0.94	0.76	0.64	0.30

(a) The standard 350-mm largemouth bass mercury concentrations are predicted values derived using the regressions in Figure 4.3.
(b) The values for the 300-400 mm bass are weighted-average concentrations in 300-400 mm largemouth bass collected between 1998 and 2000 from multiple locations within each of the five delta subareas.

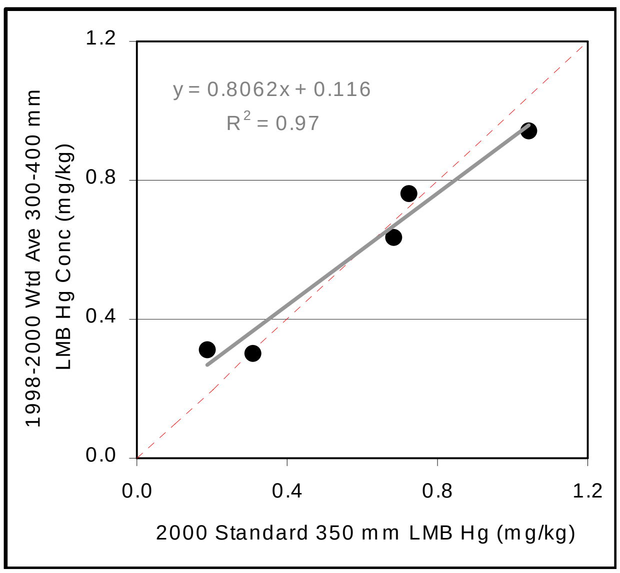

Figure 4.4: Comparison of Mercury Levels in Standard 350 mm Largemouth Bass (LMB) Collected at Linkage Sites in 2000 and Mercury Levels in 300-400 mm LMB Collected throughout Each Subarea in 1998-2000.

[23] Data collected in 1998-2000 contained individual and composite samples. Mercury concentrations in the composite samples were weighted by number of individual fish in the composite and then averaged with individual results.

4.8.3 Largemouth Bass/Trophic Level Food Group Comparisons

Regressions between mercury concentrations in standard 350-mm largemouth bass and TL3 and TL4 food groups are presented in Figure 4.5. The purpose of this analysis was to determine whether consistent relationships might exist between the different assemblages of fish and, if so, whether it might be possible to describe safe mercury ingestion rates for wildlife species and humans in terms of the mercury concentration in a standard 350-mm largemouth bass. The relationships were evaluated using linear, exponential, logarithmic and power curves; in each but one case the type of curve that provided the highest R^2 value was selected.[24] All of the correlations were statistically significant ($P<0.05$ or less). The regressions demonstrate that there are predictable relationships between mercury concentrations in standard 350-mm largemouth bass and all trophic level food groups in the Delta.

Table 4.9 presents the predicted safe dietary mercury concentrations for each target species in terms of standard 350-mm bass. The safe largemouth bass mercury levels were calculated from the regression equations in Figure 4.5. The lowest largemouth bass mercury value (0.24 mg/kg) corresponds to 0.08 mg/kg in 150-500 mm TL3 fish. This is the most conservative of all the calculated largemouth bass safe levels and, if attained, should fully protect all listed beneficial uses in the Delta. Staff recommends that **0.24 mg/kg, wet weight, in a standard 350-mm largemouth bass** be used as an **implementation goal** in the linkage analysis (Chapter 5) and determination of methylmercury allocations (Chapter 8).

As described in Tables 4.8 and 4.11, percent reductions in fish methylmercury levels ranging between 0 and 77% will be needed to meet the recommended numeric targets for large and small TL3 and TL4 fish and the implementation goal for standard 350-mm largemouth bass in the different Delta subareas. Staff expects that when methylmercury concentrations in largemouth bass reach the recommended implementation goal for standard 350-mm largemouth bass, then concentrations in other aquatic organisms also will have declined sufficiently to protect human and wildlife consumers. Monitoring should be conducted in all trophic level food groups at that time to verify that the expected decreases have occurred.

Key points and options to consider for the numeric targets are listed after Figure 4.5.

Table 4.11: Percent Reductions in Standard 350-mm Largemouth Bass Methylmercury Levels Needed to Meet the Recommended Implementation Goal of 0.24 mg/kg in Each Delta Subarea.

Central Delta	Mokelumne River	Sacramento River	San Joaquin River	West Delta
0%	77%	67%	65%	23%

[24] A logarithmic curve best fits the points comparing standard 350-mm largemouth bass mercury concentrations to 150-500 mm TL4 fish (Figure 4.3). However, the curve intercepts the x-axis well above zero, preventing the prediction of a standard largemouth bass mercury concentration that corresponds to the large TL4 fish mercury target developed for human protection (0.24 mg/kg), which is lower than average mercury concentrations observed in large Delta TL4 fish. Therefore, a linear equation with the intercept set to zero was used to estimate a standard 350-mm largemouth bass mercury concentration that corresponds to the large TL4 fish target. This regression was also statistically significant ($P<0.01$). However, use of the regression to predict a safe level for largemouth bass that corresponds to the TL4 target has additional uncertainty because the TL4 target of 0.24 mg/kg is slightly lower than the lowest (0.26 mg/kg in the Central Delta subarea) of observed values upon which the regression is based.

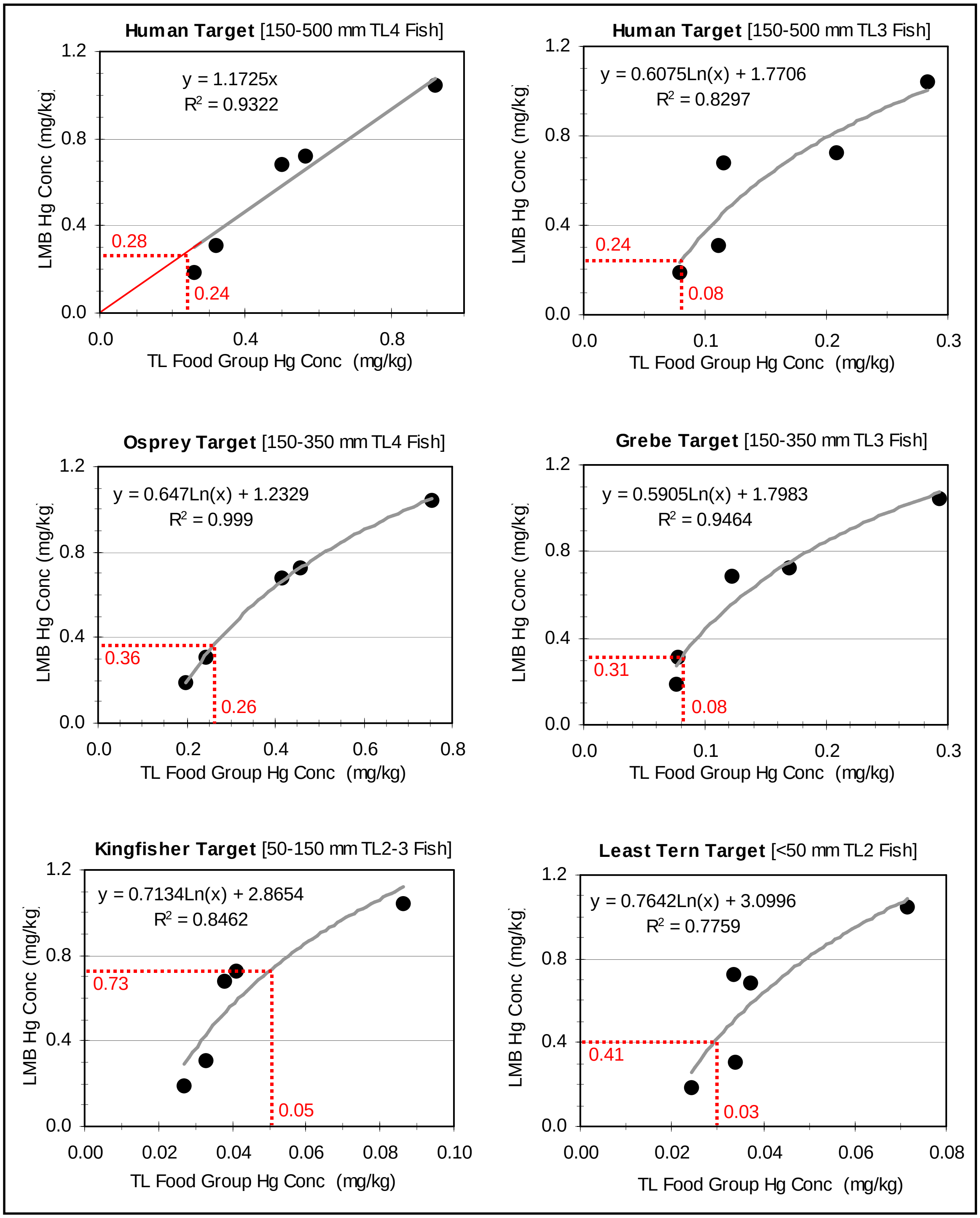

Figure 4.5: Comparison of Mercury Concentrations in Standard 350-mm Largemouth Bass (LMB) Caught in September/October 2000 and Composites of Fish from Various Trophic Level (TL) Food Groups Caught between 1998 and 2001. The regressions are used to predict safe diets for target species listed in Table 4.9 in terms of largemouth bass mercury concentrations. Note, the recommended target for large TL4 fish (0.24 mg/kg) developed for human protection is lower than average mercury levels observed in the Delta, resulting in a corresponding standard 350-mm largemouth bass concentration that falls slightly below the regression curve based on observed values.

Key Points

- The concentration of methylmercury in fish tissue is the numeric target selected for the Delta methylmercury TMDL. Measurements of mercury in fish should be able to assess whether beneficial uses are being met because fish-eating (piscivorous) birds and mammals are most likely at risk for mercury toxicity.
- Piscivorous species identified in the Delta are: American mink, river otter, bald eagle, kingfisher, osprey, western grebe, common merganser, peregrine falcon, double crested cormorant, California least tern, and western snowy plover. Bald eagles, California least terns and peregrine falcons are listed by the State of California or by USFWS as either threatened or endangered species.
- Acceptable fish tissue levels of mercury for the trophic level food groups consumed by each wildlife species were calculated using the method developed by USFWS that addresses daily intake levels, body weights and consumption rates. Numeric targets were developed to protect humans in a manner analogous to targets for wildlife using USEPA-approved methods and regional information.
- Central Valley Water Board staff recommends two numeric targets for large fish: 0.24 mg/kg (wet weight) in muscle tissue of large trophic level four (TL4) fish such as bass and catfish and 0.08 mg/kg (wet weight) in muscle tissue of large TL3 fish such as carp and salmon. These targets are protective of (a) humans eating 32 g/day (1 meal/week) of commonly consumed, large fish; and (b) all wildlife species that consume large fish. The evaluation of the relationships between methylmercury concentrations in large TL4 fish and the other trophic level food groups indicated that wildlife species that consume smaller or lower trophic level fish would be protected by the large TL3 and TL4 fish targets developed for human protection.
- To ensure that wildlife species dining only on small fish are protected, staff proposes an additional target of 0.03 mg/kg methylmercury in whole TL2 and 3 fish less than 50 mm in length. This target represents the safe level for prey consumed by the California least tern, a piscivorous species listed by the federal government as endangered. Such a target for small fish also would protect the Western snowy plover and other species that consume small fish.
- Elevated fish mercury concentrations occur along the periphery of the Delta while lower body burdens are measured in the central Delta. Percent reductions in fish methylmercury levels ranging from 0% to 74% will be needed to meet the numeric targets for wildlife and human health protection in all subareas of the Delta.
- The relationships between methylmercury concentrations in largemouth bass and the trophic level food groups also were examined because largemouth bass are a good bioindicator species and only largemouth bass data are available for the same sampling period and locations as the methylmercury water data available for the linkage analysis (next chapter). It was possible to describe safe mercury ingestion rates for wildlife species and humans in terms of the mercury concentration in a standard 350-mm largemouth bass. A methylmercury concentration of 0.24 mg/kg in 350-mm length largemouth bass would fully protect humans and piscivorous wildlife species and is proposed as an implementation goal for use in the linkage analysis and determination of methylmercury allocations for point and nonpoint sources.

Options to Consider

- A variety of assumptions can be made to calculate safe fish mercury levels for humans. For example, staff recommended targets of 0.08 mg/kg and 0.24 mg/kg for large TL3 and TL4 fish, respectively, because such targets are protective of a higher consumption rate (~1 meal/week) than that used to the develop the USEPA criterion (~1 meal/2 weeks) and because available information indicates that anglers take home a mixture of TL3 and TL4 species. Application of the USEPA criterion to large TL4 fish results in a target of 0.29 mg/kg. Use of the USEPA default consumption rates of fish from TL2 (21.7%), TL3 (45.7%) and TL4 (32.6%) produces a much higher target of 0.58 mg/kg for large TL4 fish. However, as the evaluations of trophic level food group and standard 350-mm largemouth bass mercury levels indicates, a target of 0.58 mg/kg for large TL4 fish would not protect several piscivorous wildlife species, such as bald eagle, osprey, river otter, grebe, merganser, and least tern. Large TL4 fish targets of 0.29 or 0.24 mg/kg would be protective of these species.

5 LINKAGE ANALYSIS

The Delta linkage analysis focuses on the comparison of methylmercury concentrations in water and biota. The relationship has not previously been evaluated in the Delta, but statistically significant, positive correlations have been reported between aqueous methylmercury and aquatic biota elsewhere (Brumbaugh *et al.*, 2001; Foe *et al.*, 2002; Slotton *et al.*, 2003; Tetra Tech, 2005; Sveinsdottir and Mason, 2005), suggesting that methylmercury levels in water may be one of the primary factors determining methylmercury concentrations in fish. This linkage analysis develops a Delta-specific mathematical relationship between aqueous and biotic methylmercury concentrations. The relationship is used to determine an aqueous methylmercury goal that, if met, is predicted to produce safe fish tissue levels for both human and wildlife consumption (Chapter 4). The aqueous methylmercury goal is then used to allocate methylmercury reductions for within-Delta and tributary sources (Chapter 8).

The linkage analysis has three sections. The first section describes the available fish and aqueous methylmercury data. The second section illustrates the mathematical relationship between unfiltered water and largemouth bass methylmercury levels. The mathematical relationship is used to develop an unfiltered aqueous methylmercury goal of 0.06 ng/l that is protective of all humans and wildlife that consume Delta fish. The final section provides an alternate linkage using 0.45 μ filtered methylmercury water data. Results of these correlation-based linkages are comparable to results of more empirical linkage methods, such as the evaluation of Delta areas that currently achieve the implementation goal for largemouth bass, and the use of bioaccumulation factors to calculate an aqueous methylmercury goal.

5.1 Data Used in Linkage Analysis

Fish. Water and fish have not been sampled in the Delta for the specific purpose of developing a linkage analysis. As a result, there is an acceptable overlap for only a portion of the available fish and water data. This linkage analysis focuses on recently collected largemouth bass data for several reasons. First, largemouth bass was the only species systematically collected near many of the aqueous methylmercury sampling locations used to develop the methylmercury mass balance for the Delta (next section). Second, largemouth bass are piscivorous and have some of the highest mercury levels of any fish species evaluated in the Delta. Third, bass are abundant and widely distributed throughout the Delta. Fourth, bass have high site fidelity (Davis and Greenfield, 2002), making them useful bioindicators of spatial variation in mercury accumulation in the aquatic food chain. Finally, spatial trends across the Delta in standard 350-mm largemouth bass mercury levels are representative of spatial trends in the trophic level food group mercury levels (Section 4.7). Largemouth bass were collected from 19 locations in the Delta in August/September 1998, 26 locations in September/October 1999, and 22 locations in September/October 2000 (Davis *et al.*, 2000; Davis *et al.*, 2003; LWA, 2003). The year 2000 largemouth bass data were used in the linkage analysis because the exposure period of these fish had the greatest overlap with the available water data. Monthly water data were collected during the last eight months of the life of the fish. Figure 5.1 shows the aqueous and largemouth bass methylmercury sampling locations used in the linkage analysis. The mercury concentrations in standard 350-mm largemouth bass and the corresponding water data for each sampling location are presented in Table 5.1. Section 4.8 in Chapter 4 describes the method used to calculate standard 350-mm largemouth bass mercury concentrations.

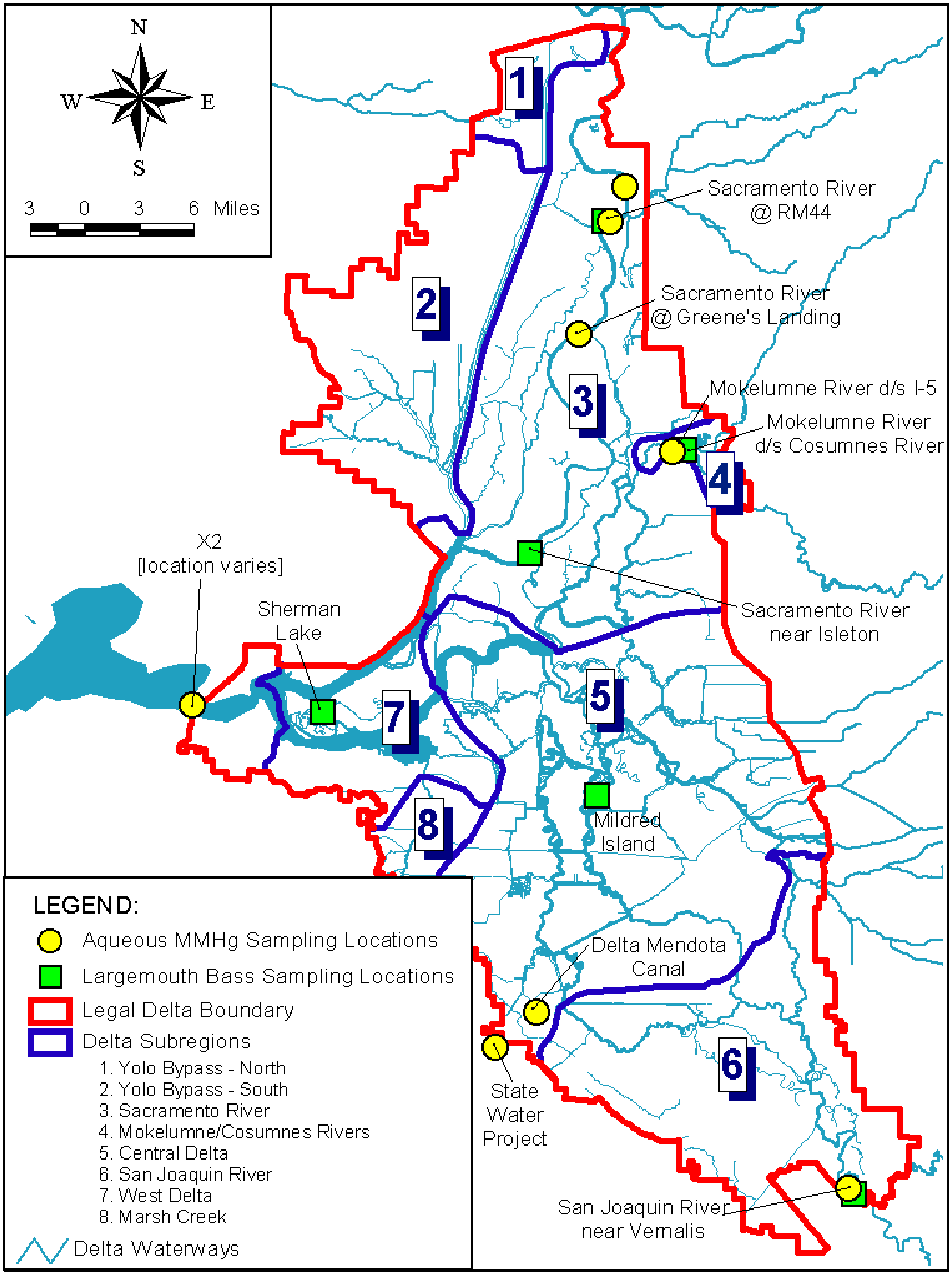

Figure 5.1: Aqueous and Largemouth Bass Methylmercury Sampling Locations Used in the Linkage Analysis.

Table 5.1: Fish and Water Methylmercury Values by Delta Subarea

	Delta Subarea (a)				
	Sacramento River	Mokelumne River	Central Delta	San Joaquin River	West Delta
FISH [Sampled in September/October 2000] (mg/kg)					
Standardized 350-mm Largemouth Bass	0.72	1.04	0.19	0.68	0.31
WATER [Sampled between March and October 2000] (ng/l)					
Average	0.120	0.140	0.055	0.147	0.087
Median	0.086	0.142	0.032	0.144	0.053
WATER [Sampled between March 2000 and April 2004] (ng/l)					
Annual Average	0.108	0.166	0.060	0.160	0.083
Annual Median	0.101	0.161	0.051	0.165	0.061
Cool Season Average (b)	0.137	0.221	0.087	0.172	0.106
Cool Season Median	0.138	0.246	0.077	0.175	0.095
Warm Season Average	0.094	0.146	0.050	0.156	0.075
Warm Season Median	0.089	0.146	0.040	0.162	0.055

(a) See Figure 5.1 for the location of each water and fish collection site.
(b) For this analysis, "cool season" is defined as November through February and "warm season" is defined as March through October.

Water. Unfiltered methylmercury water samples were collected periodically between March 2000 and April 2004 at multiple Delta locations (Figure 5.1, Appendix D). The monthly March-October 2000[25] subset of this data has the greatest overlap with the lifespan of the largemouth bass sampled in September/October 2000. The March-October 2000 and March 2000 to April 2004 data were pooled by Delta subarea to calculate monthly averages (Tables D.1 and D.2).[26] These values were used to estimate average and median methylmercury concentrations for the March-October 2000 period and annual and seasonal average and median concentrations for the March 2000 to April 2004 period (Table 5.1).[27]

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[25] Coincidentally, March through October defines the season with warmer water temperatures. Aquatic biota may be more metabolically active and have a higher methylmercury bioaccumulation rate in summer. In addition, sulfate-reducing bacteria may have higher methylmercury production rates making this a critical bioaccumulation time period.

[26] The methylmercury concentrations for two periods – (a) March-October 2000 and (b) September 2000 to April 2004 – were compared at each sampling location in Figure 5.1 with a paired t-test to determine whether the mean concentrations for the two time periods were different. The tests indicated no significant difference ($P \leq 0.05$) for any location. Therefore, the data for March 2000 to April 2004 (a substantially larger database than that for March-October 2000) were also evaluated in the linkage analysis.

[27] Monthly averages were used to ensure that the seasonal and annual values were not biased by months with different sample sizes.

5.2 Bass/Water Methylmercury Regressions & Calculation of Aqueous Methylmercury Goal

The mercury concentrations in standard 350-mm largemouth bass for each Delta subarea were regressed against the average and median unfiltered aqueous methylmercury levels for the March to October 2000 and March 2000 to April 2004 periods to determine whether relationships might exist (Figure 5.2, Table 5.2, & Figure D.1 in Appendix D). The regressions were evaluated using linear, exponential, logarithmic, and power curves. Power curves provided the best fit, although all the regression types demonstrated a positive relationship between aqueous and biotic methylmercury concentrations. In each scenario described by Table 5.2, increasing the aqueous methylmercury concentration results in increasing fish tissue levels. All the scenarios were statistically significant ($P < 0.05$).

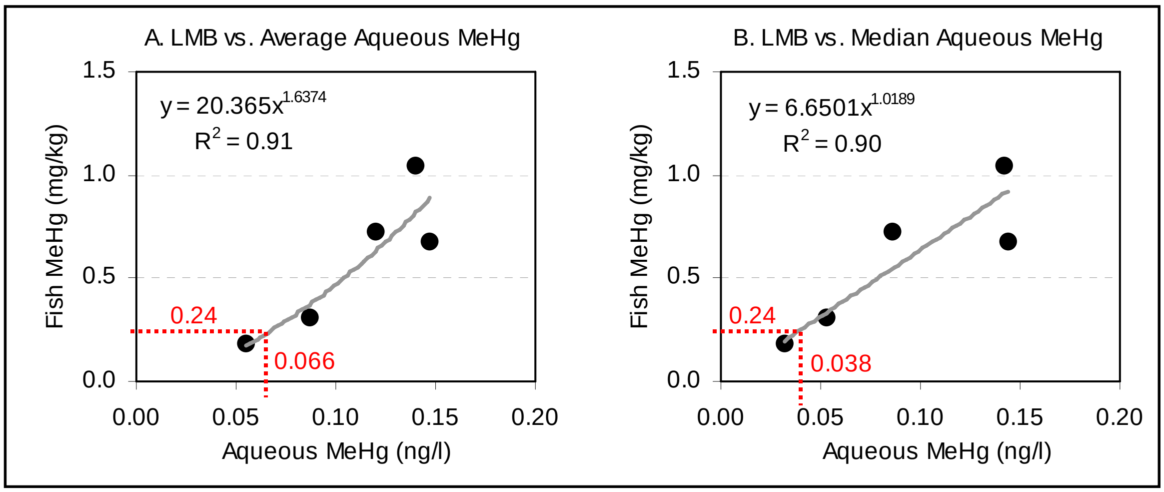

Figure 5.2: Relationships between Standard 350-mm Largemouth Bass Methylmercury & March to October 2000 Unfiltered Aqueous Methylmercury.
The proposed implementation goal for standard 350-mm largemouth bass is 0.24 mg/kg.

Table 5.2: Relationships between Methylmercury Concentrations in Water and Standard 350-mm Largemouth Bass

Aqueous MeHg Data Period	Scenario	Regression Equation	R^2 (a)	Aqueous MeHg Conc. (ng/l) Corresponding to LMB value of 0.24 mg/kg
1. March to October 2000	A. Average Aqueous MeHg	$y = 20.365x^{1.6374}$	0.91	0.066
	B. Median Aqueous MeHg	$y = 6.6501x^{1.0189}$	0.90	0.038
2. March 2000 to April 2004 - Annual -	A. Average Aqueous MeHg	$y = 14.381x^{1.51}$	0.88	0.066
	B. Median Aqueous MeHg	$y = 8.0903x^{1.1926}$	0.86	0.052
3. March 2000 to April 2004 - Cool Season -	A. Average Aqueous MeHg	$y = 17.795x^{1.8007}$	0.90	0.092
	B. Median Aqueous MeHg	$y = 8.8725x^{1.4347}$	0.92	0.081
4. March 2000 to April 2004 - Warm Season -	A. Average Aqueous MeHg	$y = 11.528x^{1.339}$	0.83	0.055
	B. Median Aqueous MeHg	$y = 6.8941x^{1.0723}$	0.85	0.044

(a) All R^2 values are statistically significant at P<0.05. Regression graphs are provided in Figure 5.2 and Appendix D.

The recommended implementation goal for methylmercury in the Delta is 0.24 mg/kg (wet weight) in a standard 350-mm largemouth bass (Chapter 4). Substitution of 0.24 mg/kg into the equations in Table 5.2

results in predicted average and median safe water methylmercury values that range from 0.04 to 0.09 ng/l. The lowest concentration is predicted by the regression based on median March to October 2000 water values (Scenario 1B) while the highest concentration is predicted by the regression based on average cool season water concentrations (Scenario 3A).

Staff recommends that **0.06 ng/l methylmercury in unfiltered water** be used as an **implementation goal** for the determination of load allocations (Chapter 8). This recommendation is based on Scenario 1A in Table 5.2 and incorporates an explicit margin of safety of about 10%. The goal could be applied as an annual average methylmercury concentration. Staff recommends this value because only the March to October 2000 period overlapped the lifespan of the largemouth bass analyzed for mercury body burden. Also, little is known about the seasonal exposure regime controlling methylmercury concentrations in aquatic biota. Therefore, an annual average was selected as it weights all seasons equally.

The linkage analysis for the Delta relies upon sequential correlations to determine the numerical aqueous methylmercury goal. A potential problem with the analysis is that each correlation has an associated error term. No attempt has been made to estimate these errors and propagate them from one correlation to the next when calculating the recommended aqueous methylmercury goal. There are two alternate, more empirical, approaches. The first approach is to compare existing largemouth bass and aqueous methylmercury levels to the proposed implementation goals. The average March-October 2000 methylmercury concentration in the Central Delta (0.055 ng/l, Table 5.1) is less than the proposed aqueous goal of 0.06 ng/l while concentrations in the West Delta (0.087 ng/l) are higher. Similarly, the methylmercury concentration in standard 350-mm bass in the Central Delta is 0.19 mg/kg while the concentration in the West Delta is 0.31 mg/kg (Table 4.10). The recommended implementation goal is 0.24 mg/kg in standard 350-mm largemouth bass. Therefore, empirical observations suggest that the "correct" aqueous methylmercury goal to achieve safe mercury levels in the various trophic level food groups must lie between 0.055 and 0.087 ng/l. If the aqueous methylmercury goal of 0.06 ng/l is attained in the Delta, then methylmercury concentrations in all trophic level food groups are predicted to fall within the safe tissue concentration range.

A second linkage approach that does not rely on the correlation between largemouth bass and water methylmercury concentrations to derive an implementation goal for water makes use of bioaccumulation factors (BAFs), an approach used in numerous USEPA-approved TMDLs across the country.[28] A BAF is the ratio of the concentration of a chemical in fish tissue to the concentration of the chemical in the water column. By definition, BAFs imply a linear relationship between methylmercury in the water column and in fish. Section D.2 in Appendix D describes the method used to develop BAF-based implementation goals for the Delta and its subregions using standard 350-mm largemouth bass and average aqueous methylmercury concentrations. The resulting safe aqueous methylmercury levels ranged from 0.029 to 0.069 ng/l, slightly less than but comparable to the safe levels produced using the regression-based approach. The similarity most likely occurs because both methods used the same fish and water data, and because the regression described in Figure 5.2(A) is nearly linear at low fish and water methylmercury levels. However, the regression-based method is preferred because it does not inherently assume a linear relationship between fish and water methylmercury levels.

The safe aqueous methylmercury concentrations predicted for the Delta are comparable to analysis results for Cache Creek and nationwide studies. Brumbaugh and others (2001) found in a national survey of

[28] Refer to: http://www.epa.gov/OWOW/tmdl/index.html.

106 stations from 21 basins that one-time unfiltered methylmercury water samples collected during the fall season were also positively correlated with largemouth bass tissue levels. An aqueous methylmercury concentration of 0.058 ng/l was predicted to produce three-year old largemouth bass[29] with 0.3 mg/kg mercury tissue concentration. In the Cache Creek watershed, an unfiltered methylmercury concentration of 0.14 ng/l corresponded with the production of 0.23 mg/kg mercury in large fish (CVRWQB, 2004). Predicted safe methylmercury water values for the Delta are bracketed by safe water concentrations determined by the national and Cache Creek studies.

Additional fish and methylmercury water studies that address uncertainties in the linkage analysis are planned. These include additional evaluations of standard 350-mm largemouth bass tissue concentrations at more locations in the Delta after multiple years of aqueous methylmercury data have been obtained. Studies also are planned to better determine the seasonal exposure regime when most of the methylmercury is sequestered in the aquatic food chain. The results of these studies may lead to future revisions in the proposed aqueous methylmercury goal.

5.3 Evaluation of a Filtered Aqueous Methylmercury Linkage Analysis

This section presents an alternate linkage analysis based on filter-passing[30] aqueous methylmercury data. Methylmercury concentrations in standard 350-mm largemouth bass for each Delta subarea (Table 5.1) were regressed against the average and median filtered aqueous methylmercury levels for March-October 2000 (Table 5.3 and Table D.3 in Appendix D). Figure 5.3 demonstrates that there is a statistically significant positive correlation between filter-passing aqueous and largemouth bass tissue methylmercury levels. However, average and median filter-passing methylmercury water values for the Central Delta and Western Delta, regions that define the lower end of the regression, are determined mainly by values lower than the method detection limit (0.022 ng/l). Furthermore, substitution of the recommended implementation goal of 0.24 mg/kg mercury for 350 mm largemouth bass in the equations in Figure 5.3 results in predicted average and median safe water values (0.016 ng/l and 0.010 ng/l, respectively) below the method detection limit. Similarly low levels resulted when the BAF-based linkage method was used (see Section D.2 in Appendix D). Staff does not recommend adoption of a methylmercury goal that is unquantifiable with present analytical methods.

Key points to consider for the linkage analysis are listed after Table 5.3 and Figure 5.3.

[29] 262-mm average length fish.

[30] Water samples were filtered using 0.45-micrometer capsule filters. Much of the methylmercury measured in filtered samples is colloidal (Choe, 2002). Hence the results are called "filter-passing" rather than "dissolved".

Table 5.3: Average and Median Filtered Methylmercury Concentrations (ng/l) for March 2000 to October 2000 for Each Delta Subarea.

	Delta Subarea (a)				
	Sacramento River	Mokelumne River	Central Delta	San Joaquin River	West Delta
Average	0.120	0.140	0.055	0.147	0.087
Median	0.086	0.142	0.032	0.144	0.053

(a) See Figure 5.1 for the location of each water and fish collection site. See Tables D.4 and D.5 in Appendix D for raw data and monthly averages, upon which these average and median values are based.

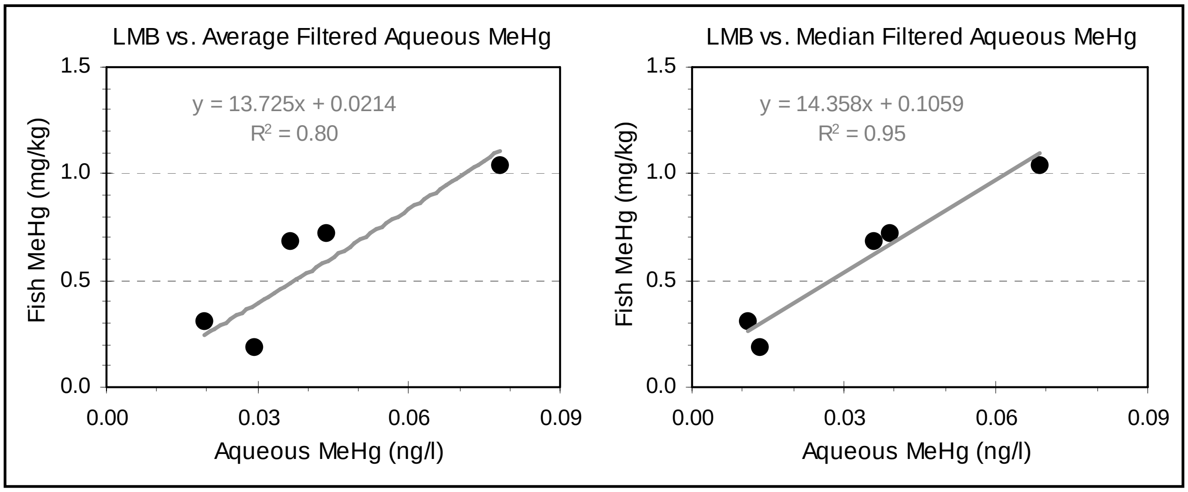

Figure 5.3: Relationships between Standard 350-mm Largemouth Bass Mercury Levels & March to October 2000 Filtered Aqueous Methylmercury.
The proposed implementation goal for standard 350-mm largemouth bass is 0.24 mg/kg.

Key Points

- Statistically significant mathematical relationships exist between unfiltered and filter-passing methylmercury concentrations in water and fish tissue.
- Based on the relationship between average March to October 2000 unfiltered methylmercury concentrations in water and methylmercury in standard 350-mm largemouth bass tissue, staff recommends an implementation goal for ambient Delta waters of 0.06 ng/l unfiltered methylmercury. The proposed goal incorporates an explicit margin of safety of about 10%. Staff recommends that the goal be applied as an annual average methylmercury concentration.
- More empirical linkage methods, such as the evaluation of Delta areas that currently achieve the implementation goal for largemouth bass and the use of bioaccumulation factors to calculate an aqueous methylmercury goal, predict safe aqueous methylmercury levels comparable to the correlation-based linkage method.

6 SOURCE ASSESSMENT – METHYLMERCURY

The Delta mercury TMDL program addresses the sources of two constituents, methyl and total mercury. The program focuses on methylmercury because, as described in Chapter 5, the Delta linkage analysis demonstrated a statistically significant, positive correlation between methylmercury levels in water and fish tissue. The program also addresses total mercury because: methylmercury production has been found to be a function of the total mercury content of sediment (Chapter 3); the mercury control program for the Delta must maintain compliance with the USEPA's CTR criterion for total recoverable mercury in freshwater sources; and the mercury control program for San Francisco Bay has assigned a total mercury load reduction of 110 kg/yr to the Central Valley (Johnson & Looker, 2004). Sources and losses of methylmercury are described in this chapter. Sources and losses of total mercury and suspended sediment are described in Chapter 7. All the mass load calculations are based on Equation 6.1:

Equation 6.1:

$$M_x = C_x * V$$

Where: M_x = Mass of constituent, X
C_x = Concentration of constituent, X, in mass per volume
V = Volume of water

Average annual methylmercury loads were estimated for water years (WY) 2000 to 2003, a relatively dry period that encompasses the available methyl and total mercury concentration data for the major Delta inputs and exports. Section 6.1 and Appendix E describe the water volumes upon which the loads are based. Sections 6.2 and 6.3 describe the methylmercury concentration data for all major sources and sinks and identify data gaps and uncertainties. Section 6.4 reviews the results and potential implications of the methylmercury mass balance. Mass balances are useful because the difference between the sum of known inputs and exports is a measure of the uncertainty of the measurements and of the importance of other unknown processes at work in the Delta.

6.1 Water Budget

Water inputs and losses were evaluated for the WY2000-2003 period, a relatively dry period that encompasses the available methylmercury concentration data for the major Delta inputs and exports (Section 6.2). In addition, the WY1984-2003 period was evaluated to illustrate the importance of wet years, particularly for total mercury and sediment loading from the Yolo Bypass (Chapter 7). This 20-year period includes a mix of wet and dry years that is statistically similar to what has occurred in the Sacramento Basin over the last 100 years. An assessment of a typical distribution of wet and dry water years is critical to the understanding of mercury and sediment sources because, as illustrated in the daily total mercury load graphs in Appendix J, the load for several high flow days may be equivalent to the annual load of the system during a dry year.

Water volume information for Delta inputs and exports was obtained from a variety of sources. USGS and DWR gages provided daily flows for the major tributaries to the Delta. The Dayflow model was used to estimate daily flow to San Francisco Bay, the Delta Mendota Canal (DMC), and the State Water Project (SWP). The Delta Island Consumptive Use Model was used to estimate Delta agricultural diversion and return flows. Average annual precipitation and land use acreages were used to estimate wet weather inputs from urban areas, atmospheric deposition, and tributaries with no flow gages. Project files were reviewed to determine average annual discharges from NPDES-permitted facilities in the Delta and annual average volumes removed by dredging projects. Appendix E provides a detailed description of the methods used to estimate annual average flow for the different water sources.

The WY2000-2003 water budget balances within about 2%, and the WY1984-2003 water budget balances to within about 1% (Table 6.1). This indicates that all major water inputs and exports have been identified. The Sacramento River, San Joaquin River and Yolo Bypass are the primary water sources, with the Sacramento River providing the majority of flow. The primary sinks are San Francisco Bay and the State and Federal pumps that transport water to the southern part of the State. The majority of water movement in the Delta is down the Sacramento River to San Francisco Bay and through a series of interconnecting channels to the State and Federal pumps. Most of the water in winter and spring flows to San Francisco Bay while in summer and fall the State and Federal pumps export a larger fraction south of the Delta (DWR, 1995).

6.2 Methylmercury Sources

The following were identified as sources of methylmercury to the Delta: tributary inflows from upstream watersheds, sediment flux, municipal wastewater, agricultural drainage, and urban runoff. Table 6.2 lists the average methylmercury concentrations and estimated average annual loads for each for WY2000-2003. The following sections illustrate the locations of the sources, describe the available methylmercury concentration data, and identify data gaps and uncertainties associated with the load estimates.

6.2.1 Tributary Inputs

Tributaries contribute more than 60% of Delta methylmercury inputs. Figure 6.1 illustrates the tributary watersheds that drain to the Delta. Several sampling efforts have taken place to characterize tributary inputs. Central Valley Water Board staff conducted monthly aqueous methylmercury sampling in the four major tributaries – Sacramento River, San Joaquin River, Mokelumne River, and Prospect Slough in the Yolo Bypass – from March 2000 to September 2001 (Foe, 2003). In addition, other programs conducted periodic aqueous methylmercury sampling on the Sacramento River between July 2000 and June 2003 (SRWP, 2004; CMP, 2004; Stephenson *et al.*, 2002). Monthly sampling by Central Valley Water Board staff resumed in April 2003. Of the three Sacramento River sampling locations included in the linkage analysis (Chapter 5) – Freeport, River Mile 44 and Greene's Landing – Freeport is the most upstream location and is used to characterize loads from the Sacramento River watershed[31] (Table 6.2).

[31] The Delta area that drains to the 13-mile reach of the Sacramento River between Freeport (near river mile 46) and the I Street Bridge (the northernmost legal Delta boundary, near river mile 59) is predominantly urban and is encompassed by the urban load estimate described in Section 6.2.5. No attempt was made to subtract this area from the Sacramento River watershed load estimate. Therefore, the Sacramento River load noted in Table 6.2 incorporates a small portion of the within-Delta urban runoff loading.

Table 6.1: Average Annual Water Volumes for Delta Inputs and Losses

Inputs & Exports	WY2000-2003		WY1984-2003	
	Water Volume (M acre-feet/yr)	% All Water	Water Volume (M acre-feet/yr)	% All Water
Tributary Sources (% of All Inputs)				
Sacramento River	15.1	78%	16.1	69%
Yolo Bypass	1	5.2%	2.7	11%
San Joaquin River	1.8	9.3%	3	13%
Mokelumne-Cosumnes River	0.48	2.5%	0.7	3.0%
Calaveras River	0.14	0.72%	0.15	0.64%
Morrison Creek	0.064	0.33%	0.067	0.29%
French Camp Slough	0.063	0.32%	0.066	0.28%
Ulatis Creek	0.030	0.15%	0.031	0.13%
Bear/Mosher Creeks	0.028	0.14%	0.029	0.12%
Marsh Creek (a)	0.006	0.03%	0.006	0.03%
Other Small Drainages to Delta (b)	0.094	0.48%	0.097	0.41%
Sum of Tributary Inputs	**18.8**	**96.9%**	**22.9**	**97.4%**
Within-Delta Sources (% of All Inputs)				
Wastewater (Municipal & Industrial) (a)	0.25	1.3%	0.25	1.1%
Atmospheric (Direct)	0.093	0.48%	0.097	0.41%
Atmospheric (Indirect)	0.15	0.77%	0.16	0.68%
Urban	0.064	0.33%	0.066	0.28%
Sum of Within-Delta Inputs	**0.56**	**2.9%**	**0.57**	**2.4%**
Exports (% of All Exports)				
Outflows to San Francisco Bay [X2]	12	63%	17	73%
State Water Project	3.2	17%	2.6	11%
Delta Mendota Canal	2.5	13%	2.4	10%
Agricultural Diversions (a)	0.99	5.2%	0.99	4.2%
Evaporation	0.30	1.6%	0.3	1.3%
Dredging (a)	0.00024	0.001%	0.00024	0.001%
Sum of Inputs	**19.4 M acre-feet**		**23.5 M acre-feet**	
Sum of Exports	**19.1 M acre-feet**		**23.3 M acre-feet**	
Input - Export	**0.3 M acre-feet**		**0.2 M acre-feet**	
Exports / Inputs	**98%**		**99%**	

(a) Only WY2001-2003 flow data were available for Marsh Creek. Wastewater volume is based on 2005 discharger information. Agricultural diversion volume is based on WY1999. The water volume removed by dredging is a 10-year average. The same water volumes for these inputs and exports were used in both water budget periods.

(b) "Other Small Drainages to Delta" include the following areas shown on Figure 6.1, for which total mercury and TSS concentration data are not available: Dixon, Upper Lindsay/Cache Slough, Manteca-Escalon, Bethany Reservoir, Antioch, and Montezuma Hills areas.

Table 6.2: Methylmercury Concentrations and Loads to the Delta for WY2000-2003.

	Average Annual Load (g/yr)	% All MeHg	Average Aqueous Concentration (ng/l)
Tributary Sources			
Sacramento River @ Freeport	2,026	41%	0.103
Yolo Bypass (a)	537	11%	0.424
San Joaquin River near Vernalis	356	7.2%	0.160
Mokelumne River near I-5	108	2.2%	0.166
Calaveras River (b)	25	0.51%	0.144
French Camp Slough (b)	11	0.22%	0.142
Bear/Mosher Creeks (b)	11	0.22%	0.310
Ulatis Creek (b)	8.9	0.18%	0.240
Morrison Creek (b)	8.1	0.16%	0.102
Marsh Creek @ Highway 4 (c)	1.9	0.04%	0.255
Other Small Drainages to Delta	*unknown*		
Sum of Tributary Sources	**3,093**	**63%**	**- - -**
Within-Delta Sources			
Sediment Flux from Wetland Habitats	767	16%	- - -
Sediment Flux from Open Water Habitats	716	15%	- - -
Wastewater (d)	194	3.9%	<0.02 to 1.689
Agricultural Lands	123	2.5%	0.352
Urban	21	0.43%	0.241
Atmospheric Deposition	8.5	0.17%	- - -
Sum of Within-Delta Sources	**1,830**	**37%**	**- - -**
TOTAL MeHg INPUTS:	**4,922 g/yr (4.9 kg/yr)**		

(a) The Yolo Bypass load is based on average MeHg concentrations in Prospect Slough when the Lisbon Weir had a net outflow.
(b) Average wet weather methylmercury concentrations are shown for the small watersheds rather than average annual concentrations.
(c) Only WY2001-2003 flow data were available for Marsh Creek.
(d) Wastewater MeHg loads are based on MeHg concentration data and discharge volumes observed in 2004-2005, while the river and within-Delta nonpoint source loads are based on WY2000-2003, a relatively dry period. Wastewater loads could represent a smaller fraction of the MeHg loading to the Delta during wet years.

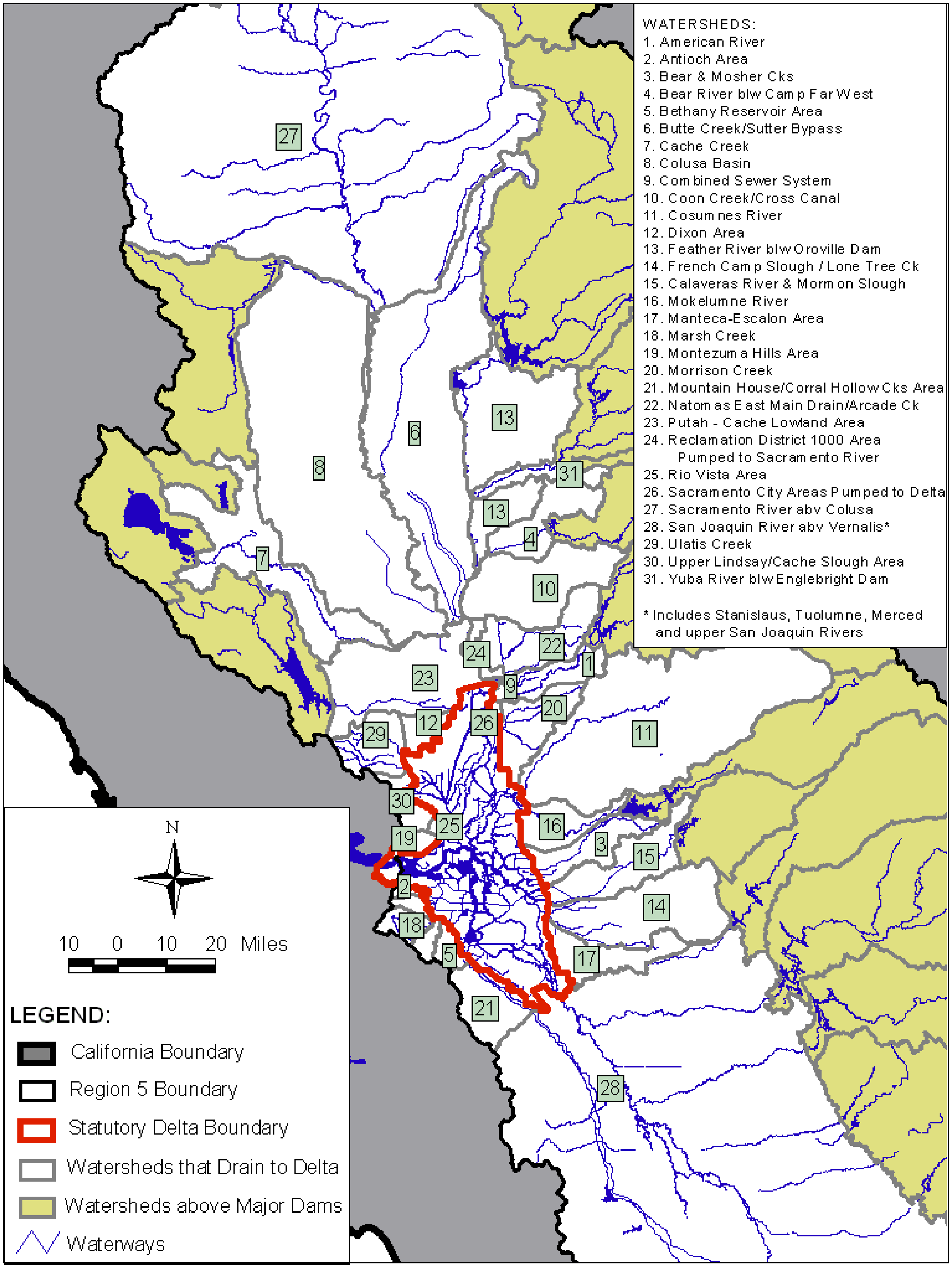

Figure 6.1: Watersheds that Drain to the Delta.

Figure 6.2 shows the tributary methylmercury monitoring locations. Figure 6.3 and Table 6.3 summarize the available methylmercury concentration data for tributary sources. Regressions between methylmercury concentration and daily flow were evaluated for each tributary input to determine whether concentrations could be predicted from flow (Appendix F). Only the regression for the Sacramento River was significant ($P<0.05$). The Sacramento River regression explained 12% of the variation in methylmercury concentrations. Lack of a relationship between methylmercury concentrations and flow at all sites except the Sacramento River suggests that flow is unlikely to be a useful surrogate for methylmercury concentrations. The relationship at Freeport may be a statistical anomaly. Therefore, average methylmercury concentrations were used to estimate all tributary loads. For tributary inputs with a monthly sampling frequency (Table 6.3), concentration data were pooled by month to calculate monthly average concentrations for WY2000-2003 (Appendix F). The monthly average concentrations were multiplied by monthly average flow volumes to estimate loads; monthly loads were summed to calculate an annual average methylmercury load for WY2000-2003. For all the tributaries with less frequent sampling, loads were estimated by multiplying average annual water volume for WY2000-2003 (Table 6.1) by the average wet weather methylmercury concentration for each tributary input (Table 6.3). Although sampling took place on a regular basis at Prospect Slough in the Yolo Bypass, only five sampling events occurred when there was net advective outflow at the Lisbon Weir (Appendix E, Section E.2.2). Dispersive or tidal flows also transport loads from the Bypass below the Lisbon Weir during almost all times; however, the actual amount is unknown at present. Therefore, loads from the Yolo Bypass were estimated by multiplying average methylmercury concentrations observed when the Yolo Bypass had net outflow (0.424 ng/l) by the annual average net advective outflow (1.0 M acre-ft/yr). The resulting loads probably underestimate export from the Bypass.

The Sacramento River was the primary tributary source of methylmercury (2.0 kg/yr) during WY2000-2003 (Table 6.2). LWA (2002) calculated an annual average methylmercury load of 3.2 ±1.6 kg/yr for the Sacramento River at Freeport for 1980-1999 (a wetter period than the TMDL base period). Foe (2002) also concluded that the Sacramento River was the major methylmercury tributary source in all months between March 2000 and September 2001, except for March 2000 when the Yolo Bypass was flooded and it became the primary source of methylmercury. Water years 2000 through 2003 were considered normal to dry years in the Sacramento and San Joaquin watersheds (Appendix E, Section E.1). Therefore, tributary loads for the TMDL study period may underestimate long-term values. In particular, the Yolo Bypass may provide a more substantial methylmercury load to the Delta when flooded for prolonged periods, as in 1997 and 1998.

The Central Valley Water Board is continuing to monitor methylmercury on all major tributary inputs to the Delta. The results will be compiled and a report written in the fall of 2006.

6.2.2 Within-Delta Sediment Flux

Within-Delta sediment flux is estimated to contribute about 30% of the overall methylmercury load (Table 6.2). Methylmercury loads from bottom sediment in open water were estimated from flux rates measured by Gill and others (2003). Wetland flux rates were from Heim, Sassone and others (Heim *et al.*, 2004; Sassone *et al.*, 2004) and a load calculation method outlined by Heim and others (Heim *et al.*, 2004; Heim, personal communication). To measure methylmercury flux in open water habitats, Gill and others

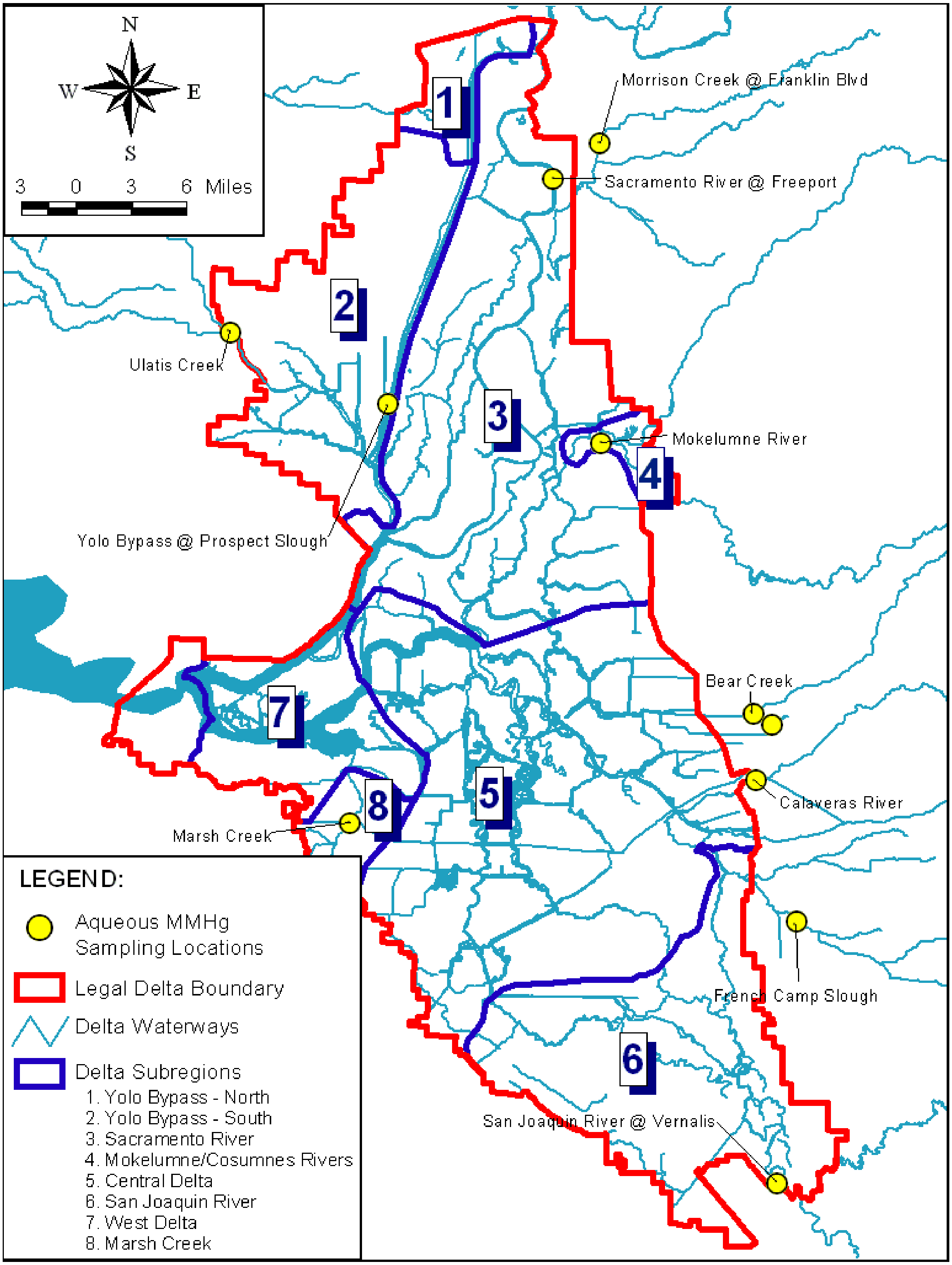

Figure 6.2: Tributary Aqueous Methylmercury Monitoring Locations

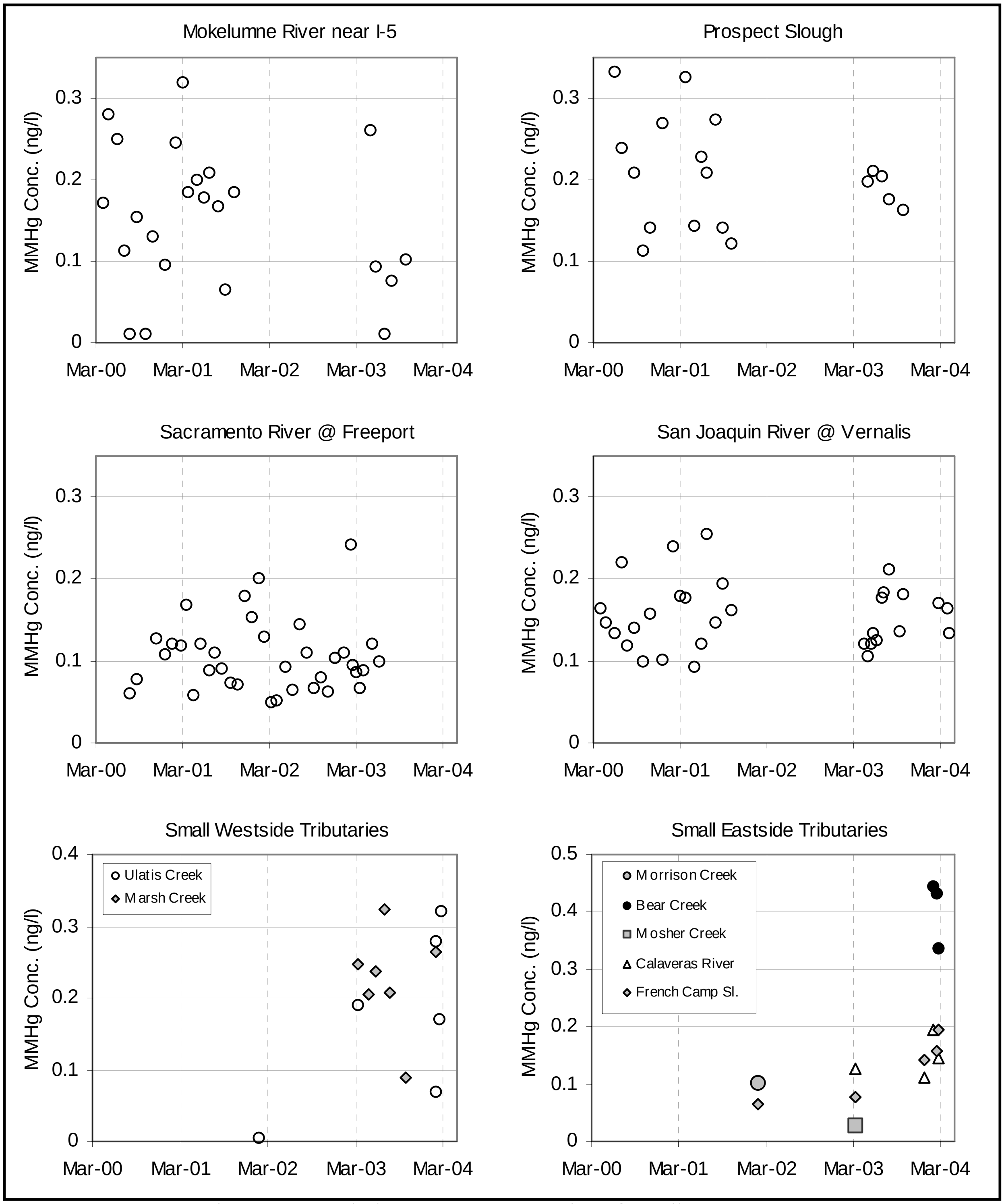

Figure 6.3: Methylmercury Concentrations for Tributary Inputs

Table 6.3: Methylmercury Concentrations for Tributary Inputs

Site	# of Samples	Sampling Begin Date	Sampling End Date	Min. MeHg Conc. (ng/l)	Ave. MeHg Conc. (ng/l)	Annual Ave. MeHg (ng/l) (a)	Median MeHg Conc. (ng/l)	Max. MeHg Conc. (ng/l)
Large Tributaries to the Delta								
Mokelumne River @ I-5	23	3/28/00	9/30/03	0.011	0.153	0.166	0.167	0.320
Prospect Slough (Yolo Bypass) (b)	22 (5)	3/28/00	9/30/03	0.114 (0.197)	0.256 (0.424)	0.273 (0.424)	0.209 (0.413)	0.701 (0.701)
Sacramento River @ Freeport	36	7/18/00	6/11/03	0.050	0.105	0.103	0.097	0.242
San Joaquin River @ Vernalis	31	3/28/00	4/12/04	0.093	0.156	0.160	0.147	0.256
Small Tributaries to the Delta								
Bear Creek @ West Lane	3	2/2/04	2/26/04	0.336	0.404	0.310	0.431	0.446
Calaveras River @ RR u/s West Lane	4	3/15/03	2/26/04	0.110	0.144	0.144	0.137	0.193
French Camp Slough d/s Airport Way	5	1/28/02	2/26/04	0.063	0.127	0.142	0.143	0.193
Marsh Creek @ Hwy 4	7	3/15/03	2/2/04	0.090	0.224	0.255	0.237	0.323
Morrison Creek @ Franklin	1	1/28/02	1/28/02	0.102	0.102	0.102	0.102	0.102
Mosher Creek @ Morada Lane (c)	1	3/15/03	3/15/03	0.028	0.028	(c)	0.028	0.028
Ulatis Creek near Main Prairie Rd	6	1/28/02	2/26/04	0.004	0.172	0.240	0.180	0.322

(a) For the large tributary inputs, methylmercury concentration data were pooled by month to estimate monthly average methylmercury concentrations and loads (Tables Q.1 and Q.2); the monthly average loads were summed to estimate annual average methylmercury loads for water years 2000-2003. The methylmercury concentration data are listed in Table D.1 in Appendix D. The monthly average concentrations and flows are listed in Appendix F. The monthly average concentrations were averaged to estimate annual average concentrations, which were included in Table 6.2. Sampling on the small tributaries did not take place monthly. In addition, flow gages were unavailable for these tributaries. Therefore, wet weather methylmercury concentration data were averaged to estimate annual average methylmercury concentrations and loads.

(b) Only five Prospect Slough MeHg sampling events took place when there was a net outflow. These sampling events are described in parentheses. Methylmercury concentrations during other times were strongly affected by tidal pumping of waters from the Sacramento River.

(c) The one Mosher Creek sample result was combined with the Bear Creek methylmercury data to estimate methylmercury loads for both creeks.

(2003) deployed benthic flux chambers at nine locations in the Bay-Delta region during five separate field-sampling efforts between May 2000 and October 2001. This study estimated a methylmercury flux rate of approximately 10 ng/m^2/day for open water habitat. An additional study of sediment-water MeHg flux within marsh and wetland habitat was conducted at two experimental ponds on Twitchell Island (Heim *et al.*, 2004; Sassone *et al.*, 2004). The pond with more shallow water and greater coverage of emergent vegetation had sediment-water flux rates of 41 ng/m^2/day and 3 ng/m^2/day during June and October 2003, respectively. Heim (personal communication) recommended that these flux rates be used to estimate warm and cool season loads; the warm season was defined as March through September (214 days) and the cool season as October through February (151 days).

Wetland and open water acreages were estimated using the 1997 National Wetland Inventory coverage for the Delta region (Figure 6.4). Types of wetland habitat in the Delta are predominantly seasonal wetlands and tidal, salt, brackish and freshwater marshes. The open-water, warm season wetland and cool season wetland flux rates were multiplied by the open water and wetland areas, respectively, to estimate daily loading. The daily loads were multiplied by the number of days in the warm and cool seasons and then summed to estimate annual loading. The loads to each Delta subarea were calculated (Table 6.4) to develop subarea-specific allocations (Chapter 8). The Yolo Bypass subarea has the greatest methylmercury loading from sediment because it has the greatest acreage of wetlands; the Central Delta subarea is second because it has the greatest amount of open water habitat. Sediment loading for each subarea was summed so that a Delta-wide sediment load could be compared with other sources in Table 6.2.

Texas A&M and Moss Landing Marine Laboratory are conducting additional benthic loading studies to better define methylmercury sediment flux rates from different types of wetlands and other habitats. The results of these studies should become available in the fall/winter of 2006.

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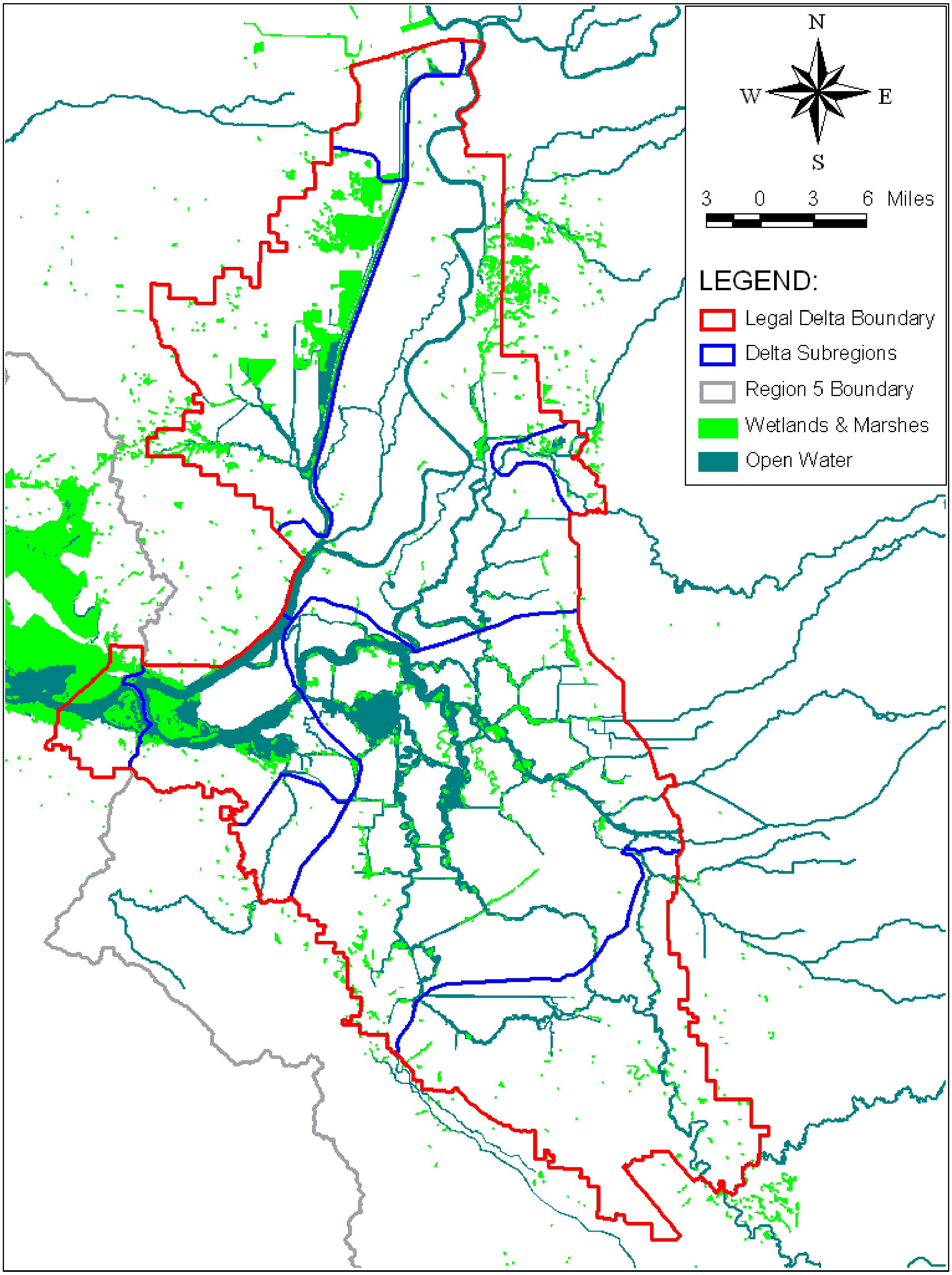

Figure 6.4: Delta Wetlands and Open Water Habitat. Wetland areas include seasonal wetlands and brackish and freshwater marshes. (Wetland and open water coverage source: NWI, 1997. This figure does not include wetlands to the east of the Delta.)

Table 6.4: Methylmercury Loading from Wetland and Open Water Habitats in Each Delta Subarea. (a)

	Central Delta	Cosumnes / Mokelumne River	Marsh Creek	Sacramento River	San Joaquin River	West Delta	Yolo Bypass-North	Yolo Bypass-South	Grand Total
Open Water Habitats									
Open Water (acres):	20,402	77	2.2	7,973	1,325	12,833	665	5,162	**48,439**
% of Total Water Area	*42%*	*0.2%*	*0.00%*	*16%*	*2.7%*	*26%*	*1.4%*	*11%*	***100%***
Open Water (m2):	82,564,182	313,064	9,057	32,264,813	5,364,032	51,931,998	2,690,703	20,890,049	**196,027,898**
Daily Open Water MeHg Load (g/day) (b):	0.8	0.0031	0.0001	0.32	0.05	0.52	0.03	0.21	**2.0**
Annual Open Water MeHg Load (g/year):	301	1.1	0.03	118	20	190	10	76	**716**
Wetland Habitats (c)									
Wetland Area (acres):	3,663	324	11	1,786	478	3,271	377	10,832	**20,743**
% of Total Wetland Area	*18%*	*1.6%*	*0.05%*	*8.6%*	*2.3%*	*16%*	*1.8%*	*52%*	***100%***
Wetland Area (m2):	14,822,447	1,312,118	43,666	7,229,269	1,936,349	13,237,507	1,524,382	43,837,692	**83,943,430**
Warm Season MeHg Daily Load (g/day):	0.60	0.05	0.002	0.29	0.08	0.54	0.06	1.8	**3.4**
Cool Season MeHg Daily Load (g/day):	0.044	0.004	0.0001	0.022	0.006	0.040	0.005	0.13	**0.25**
Annual Wetland MeHg Load (g/year):	135	12.0	0.40	66	18	121	14	401	**767**
Annual MeHg Load (grams/year):	**437**	**13**	**0.43**	**184**	**37**	**311**	**24**	**477**	**1,483**

(a) Wetland and open water habitat acreages were obtained from the National Wetland Inventory (NWI, 1997).
(b) The daily open water MeHg load for each Delta subarea was estimated by multiplying its open water area by the open water sediment flux rate, 10 ng/m2/day. The open water MeHg flux rate was developed by Gill and others using benthic flux chambers (Gill *et al.*, 2003).
(c) The daily warm season and cool season wetland MeHg loads for each Delta subarea were estimated by multiplying the open water area by the warm and cool season wetland flux rates, 41 ng/m2/day and 3 ng/m2/day. The warm and cool season wetland flux rates were developed by Heim and others (2004) using direct measurement of MeHg concentrations in inflows and outflows from test wetlands on Twitchell Island in the west Delta. The warm season for the wetland flux rate is defined approximately as March through September (214 days) and the cool season is defined approximately as October through February (151 days) (Heim, personal communication). The annual load was estimated by multiplying the number of days in the warm and cool seasons by the daily warm and cool season loads, respectively, and summing the resulting seasonal loads.

6.2.3 Municipal & Industrial Sources

Twenty NPDES-permitted municipal and industrial dischargers are located in the Delta (Figure 6.5, Table 6.5). These facility discharges account for about 4% of the annual methylmercury loading to the Delta (Table 6.2). Information on the facilities is from the State Water Resources Control Board's Surface Water Information (SWIM) database. Information on average flows rates for each facility was obtained from the Central Valley Water Board's discharger project files and permits. Appendix G provides additional information about the facilities.

Between December 2000 and December 2001, the Sacramento Regional County Sanitation District (SRCSD) collected 45 samples to characterize its effluent methylmercury levels. In February and March 2004, Central Valley Water Board staff conducted two sampling events at four municipal wastewater treatment plants (WWTPs)[32] to determine whether the SRCSD data are representative of other municipal wastewater treatment plants' effluent methylmercury levels. The 2004 sampling results indicated that the methylmercury data from the SRCSD facility may not be representative of other facilities in the Delta region. Therefore, the Central Valley Water Board issued a California Water Code Section 13267 order in July 2004 requiring municipal WWTPs and other dischargers located in the Delta and downstream of major dams in the Delta's tributary watersheds to monitor and characterize their effluent. Table 6.5 summarizes the results of available methylmercury data for facility discharges in the Delta. Appendix G provides a preliminary summary of the methylmercury data generated by sampling efforts throughout the Delta and its tributary watersheds to date. Appendix H provides a copy of the letter and a list of facilities that received the Section 13267 order.

Thirteen of the Delta facilities are municipal wastewater treatment plants. Average annual methylmercury loads were calculated for each municipal WWTP using the average MeHg concentration based on available data and the annual discharge volume for 2005. Facility-specific average effluent MeHg concentrations ranged from less than 0.02 ng/l (Brentwood and Deuel Vocational Institute WWTPS) to 1.9 ng/l (SRCSD Walnut Grove WWTP). The variability in the MeHg concentrations observed in effluent from different municipal WWTPs in the Delta is comparable to WWTP effluent concentrations observed elsewhere. A study that evaluated MeHg concentrations in three domestic sewage treatment plants at the City of Winnipeg, Canada, found average effluent MeHg concentrations to be very low at two facilities (0.13 to 0.56 ng/l, no seasonal trend) and higher at a third (greater than 2 ng/l, with highest concentrations in the summer) (Bodaly *et al*., 1998). A separate study that evaluated seasonal patterns in sewers and wastewater unit processes in the Onondaga County Metropolitan Wastewater Treatment Plant in Syracuse, New York, observed a mean MeHg concentration of 1.63 ± 1.19 and 1.43 ± 0.671 ng/l[33] in warm and cool months, respectively; a peak of 3.70 ng/l was measured in May (McAlear, 1996). Cool weather sampling at the San Jose/Santa Clara Water Pollution Control Plant in California indicated an average effluent MeHg concentration of 0.029 ng/l (n=16) (City of San Jose, 2005).

[32] Central Valley Water Board staff also conducted sampling at one power plant. The Mirant Delta Contra Costa Power Plant withdraws San Joaquin River water for use as cooling water and discharges back to the San Joaquin River. Central Valley Water Board staff selected this plant for methylmercury sampling for two reasons: (1) to determine if the use of ambient water for cooling water caused any measurable increase in methylmercury levels, and (2) because the plant has the largest daily and annual discharge volume in Region 5. Based on the comparison of intake and outfall data, Mirant Delta's Contra Costa Power Plant did not appear to be a source of new methylmercury to the Delta (Table G.5b).

[33] Mean concentration ± standard deviation.

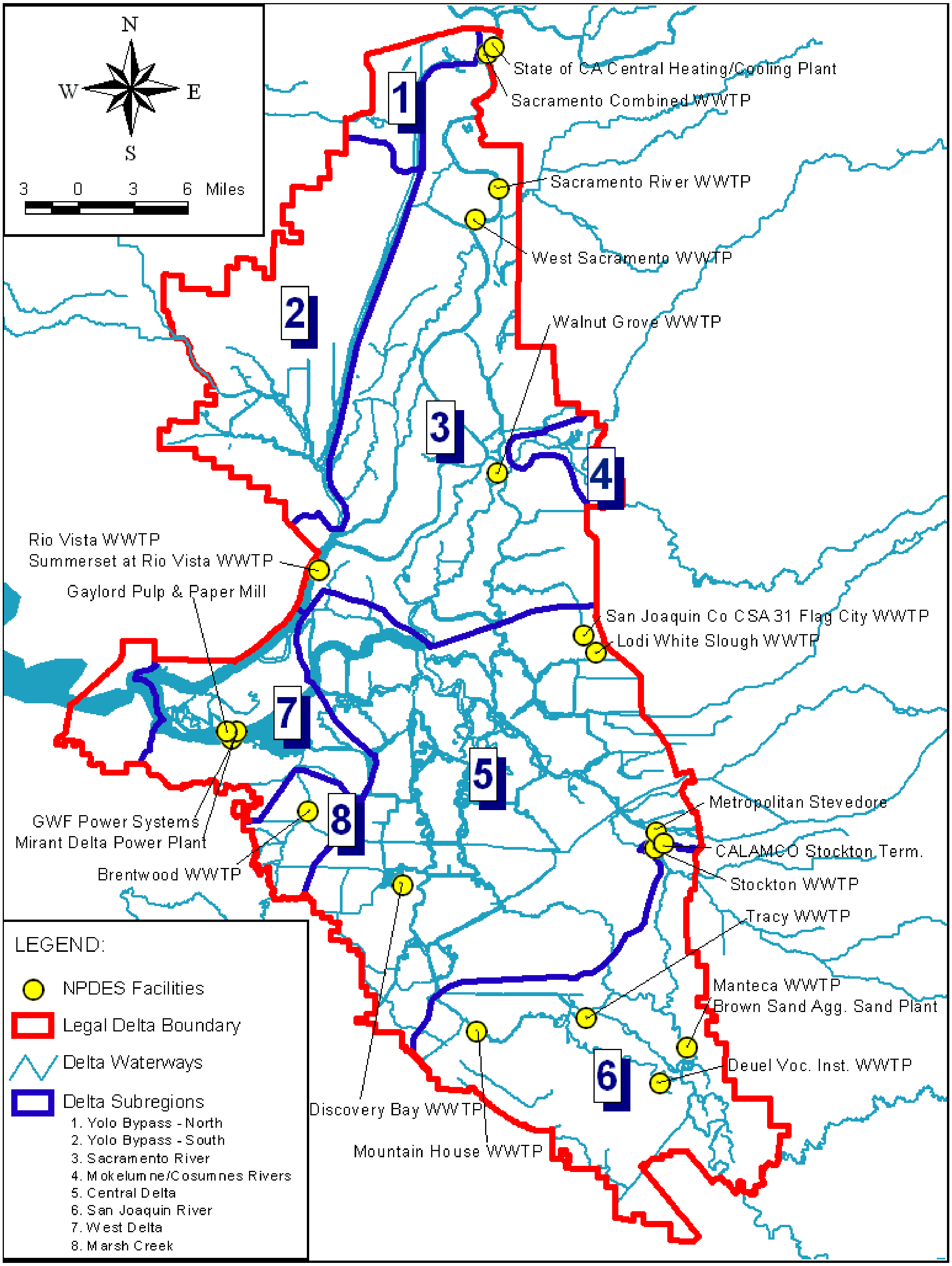

Figure 6.5: NPDES Facilities within the Statutory Delta Boundary.

Table 6.5: Summary of Unfiltered Methylmercury Concentration Data for Effluent from NPDES-permitted Facilities in the Delta. (a)

Facility Name	NPDES #	Facility Type	Delta Subarea	# of MeHg Sampling Events	Average Conc. (ng/l) (b)	Conc. Range	# of Nondetect Results	MeHg Sampling Period	Average Daily Discharge for WY2005 (mgd)	Annual MeHg Load (g/yr)
Brentwood WWTP	CA0082660	POTW	Marsh Ck	13	0.02	0.02-0.02	13	8/04-8/05	3.09	0.043
CALAMCO Stockton Terminal	CA0083968	Heating /Cooling	Central	4	0.29	0.030-0.919	0	8/04-8/05	5.06	2.0 (c)
Deuel Vocational Institute WWTP	CA0078093	POTW	San Joaquin	4	0.02	0.02-0.02	4	10/04-6/05	0.47	0.0064
Discovery Bay WWTP	CA0078590	POTW	Central	12	0.20	0.025-2.03	7	8/04-7/05	1.54	0.41
GWF Power Systems	CA0082309	Power	West	4	0.03	0.025-0.025	4	8/04-5/05	0.05	0.00081 (c)
Lodi White Slough WWTP	CA0079243	POTW	Central	12	0.13	0.02-1.24	4	8/04-7/05	3.97	0.70
Manteca Aggregate Sand Plant	CA0082783	Lake Dewatering	San Joaquin	2	0.03	0.02-0.043	1	8/04-11/04	9.15	0.34
Manteca WWTP	CA0081558	POTW	San Joaquin	11	0.22	0.037-0.356	0	9/04-7/05	4.63	1.4
Mirant Delta LLC Contra Costa Power Plant (Outfall 1)	CA0004863	Power	West	12	0.07	0.02-0.121	1	2/04-5/05	2.90	0.30 (c)
Mirant Delta LLC Contra Costa Power Plant (Outfall 2)	CA0004863	Power	West	10	0.09	0.042-0.15	0	2/04-3/05	121.03	14 (c)
Rio Vista WWTP	CA0079588	POTW	Sacramento	4	0.16	0.035-0.522	0	8/04-4/05	0.47	0.11
Rio Vista Trilogy WWTP	CA0082848	POTW	Sacramento						0.10	Tbd
San Joaquin Co DPW CSA 31 Flag City WWTP	CA0082848	POTW	Central	3	0.09	0.025-0.152	1	1/05-10/05	0.06	0.0065
SRCSD Sacramento River WWTP	CA0077682	POTW	Sacramento	45	0.73	0.144-2.93	0	12/00-12/01	151.42	152
SRCSD Walnut Grove WWTP	CA0078794	POTW	Sacramento	3	1.69	0.759-3.36	0	12/04-4/05	0.08	0.19
State of California Central Heating/Cooling Plant	CA0078581	Heating /Cooling	Sacramento	4	0.02	0.02-0.029	3	8/04-6/05	5.26	0.11 (c)
Stockton WWTP	CA0079138	POTW	San Joaquin	12	0.94	0.02-2.09	1	8/04-7/05	27.78	36
Tracy WWTP	CA0079154	POTW	San Joaquin	13	0.15	0.025-0.422	1	8/04-8/05	9.49	1.9
West Sacramento WWTP	CA0079171	POTW	Sacramento	12	0.05	0.02-0.085	1	8/04-7/05	5.60	0.39

(a) No methylmercury data are yet available for Metropolitan Stevedore (CA0084174), a power facility in the Central Delta subarea, and the Sacramento Combined WWTP (CA0079111; see Table G.2 in Appendix G) in the Sacramento River subarea. In addition, Mountain House CSD WWTP (CA0084271) is not yet discharging to surface water.

(b) Analytical method detection limits were 0.025 ng/l or less. One half the detection limit was used for nondetect values to calculate the average methylmercury concentrations and loads.

(c) Based on the comparison of the available intake and outfall methylmercury data (Table G.4 in Appendix G), power and heating/cooling facilities that use ambient water for cooling water do not appear to act as a source of new methylmercury to the Delta. This assumption will be re-evaluated as additional information becomes available.

Some type of seasonal or other treatment-related variability was observed in effluent methylmercury concentrations at several of the municipal WWTPS in the Delta and its tributary watersheds (e.g., Anderson, Chico, Davis, Manteca, SRCSD Sacramento River, Stockton, Tracy and Yuba City WWTPs; see Figures G.2 and G.3 in Appendix G). Identifying the reasons why some facilities discharge effluent with higher methylmercury concentrations than others, and why some facilities have seasonal or other treatment-related variability in their methylmercury discharges, could be critical components to the development of methylmercury controls.[34]

Five of the facilities in the Delta are power or heating/cooling facilities that use ambient water for cooling water. Based on the comparison of the available intake and outfall methylmercury data (Table G.4 in Appendix G), the facilities do not appear to act as a source of new methylmercury to the Delta. This assumption will be re-evaluated as additional information becomes available.

The Manteca Aggregate Sand Plant NPDES permit (CA0082783) allows flood-control pumping from Oakwood Lake, a former excavation pit filled primarily by groundwater, to the San Joaquin River. The results from discharge sampling in August and November 2004, nondetect (<0.02 ng/l) and 0.043 ng/l respectively, are comparable to groundwater treatment plant discharges in the Delta's tributary watersheds (refer to Table G.3 in Appendix G) and are substantially lower than the monthly average methylmercury concentrations observed in the San Joaquin River at Vernalis during August and November (0.167 and 0.130 ng/l, respectively; refer to Table F.1 in Appendix F). Average annual methylmercury loading from Oakwood Lake was estimated using a methylmercury concentration of 0.03 ng/l and the average annual discharge volume.

The City of Sacramento owns and operates a combined sewer system (CSS) that serves about eleven thousand acres. The CSS conveys up to 60 mgd of domestic and industrial wastewater and storm runoff to the SRCSD's Sacramento River WWTP. The City of Sacramento operates its Combined Wastewater Treatment Plant (CA0079111) only when combined wastewater/storm flows exceed 60 mgd (Table G.2 in Appendix G). The plant provides primary treatment with disinfection. The CSS discharges to receiving waters only when storm flows exceed total treatment and storage capacity. Discharges are predominantly urban storm runoff. No methylmercury data are available yet for Combined Wastewater Treatment Plant or untreated CSS discharges. Therefore, the average methylmercury concentration in wet weather urban runoff (0.241 ng/l, see Section 6.2.5) and average annual discharge volume (464 million gallons/year, see Table G.2b) were used to estimate a CSS methylmercury load of 0.43 g/yr.

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[34] In addition, seasonal increases in effluent methylmercury loading from some facilities could result in a greater influence on local water bodies. For example, SRCSD Sacramento River WWTP (the largest permitted facility discharge in the Central Valley) has an annual effluent methylmercury load (151 g/yr, see Table 6.5) that averages about 8% of its receiving water load (2,026 g/yr, Sacramento River at Freeport, see Table 6.2). During the wet season, SRCSD daily effluent loads ranged between 2 and 12% of river loads, and daily effluent volumes averaged about 2% of river volume (Table G.4 in Appendix G). However, during the dry season, SRCSD daily effluent loads ranged between 16 and 30% of river loads while effluent volume remained about 2% of river volume. Currently, little is known about the seasonal exposure regime controlling methylmercury concentrations in aquatic biota. Therefore, this TMDL is based on annual average source loads to weight all seasons equally. However, studies are planned to better determine the seasonal exposure regime when most of the methylmercury is sequestered in the aquatic food chain; results from these studies may lead to future revisions in the TMDL. Seasonal discharge information is not yet available for most methylmercury sources to the Delta, but would be required by the source control and characterization studies proposed by the draft implementation plan described in Chapter 4 of the Proposed Basin Plan Amendment draft staff report.

6.2.4 Agricultural Return Flows

More than half a million acres of the Delta islands are under agricultural production (Figure 6.6). Water seeps and is diverted onto the islands for irrigation from the surrounding river channels. The unused water is returned to Delta waterways via a series of main drains. Many of the islands are predominately peat, a substance that Gill and others (2003) and Heim and others (2003) have shown to be a good substrate for methylmercury production. Water samples collected from five Delta Island main drains in June and July 2000 suggest that the agricultural islands are net exporters of unfiltered methylmercury (Foe, 2003). Methylmercury concentrations were variable but high compared to concentrations in the river channels surrounding the islands from which the irrigation supply water was diverted and unused tail-water returned. Agricultural return flow concentrations averaged 0.35 ng/l in June and July 2000 while concentrations in the supply water was 0.07 ng/l (Tables 6.6 and 6.7). This translates to a net production rate of approximately 17 to 35 grams per month (~0.5 to 1.1 g/day) if occurring over the entire Delta or 10 to 25% of all river loading in the two-month period.

The annual methylmercury load from agricultural lands located in the Delta was estimated to be 123 g/yr (Table 6.2). Delta agricultural diversion and return flow estimates were obtained from the Delta Island Consumptive Use Model for water year 1999, the year during which the majority of agricultural drain methylmercury data were collected (Table 6.8). The annual diversion and return flow water volumes were multiplied by their respective methylmercury concentrations to estimate annual loads. For this preliminary evaluation, the average of available agricultural drain methylmercury data (Table 6.6) was used to estimate methylmercury concentrations in all Delta agricultural return flows. The methylmercury concentration of river diversions was estimated by averaging monthly Sacramento River and State Water Project MeHg concentrations between May and December (Appendix D, Table D.3). To estimate the methylmercury loading from agricultural lands, the estimated methylmercury load in the river waters diverted onto the islands was subtracted from the agricultural return loads (Table 6.6), resulting in a net input of 123 grams per year. This load was multiplied by the percentage of total agricultural acreage located in each Delta subarea to estimate a subarea specific loading rate (Table 6.9). The Central Delta and Sacramento River subareas have the greatest estimated methylmercury loading from agricultural lands because they have the largest acreage of agricultural land.

This preliminary evaluation indicates that agricultural runoff may contribute about 2.5% of the methylmercury load to the Delta. However, Central Valley Water Board staff recognizes that agricultural loads have not been adequately characterized. Staff recommends that a follow-up study be undertaken to more fully monitor and characterize loads from Delta Islands and, if elevated, determine the primary land uses responsible for methylmercury production. The study should be done in cooperation with agricultural interests in the Delta.

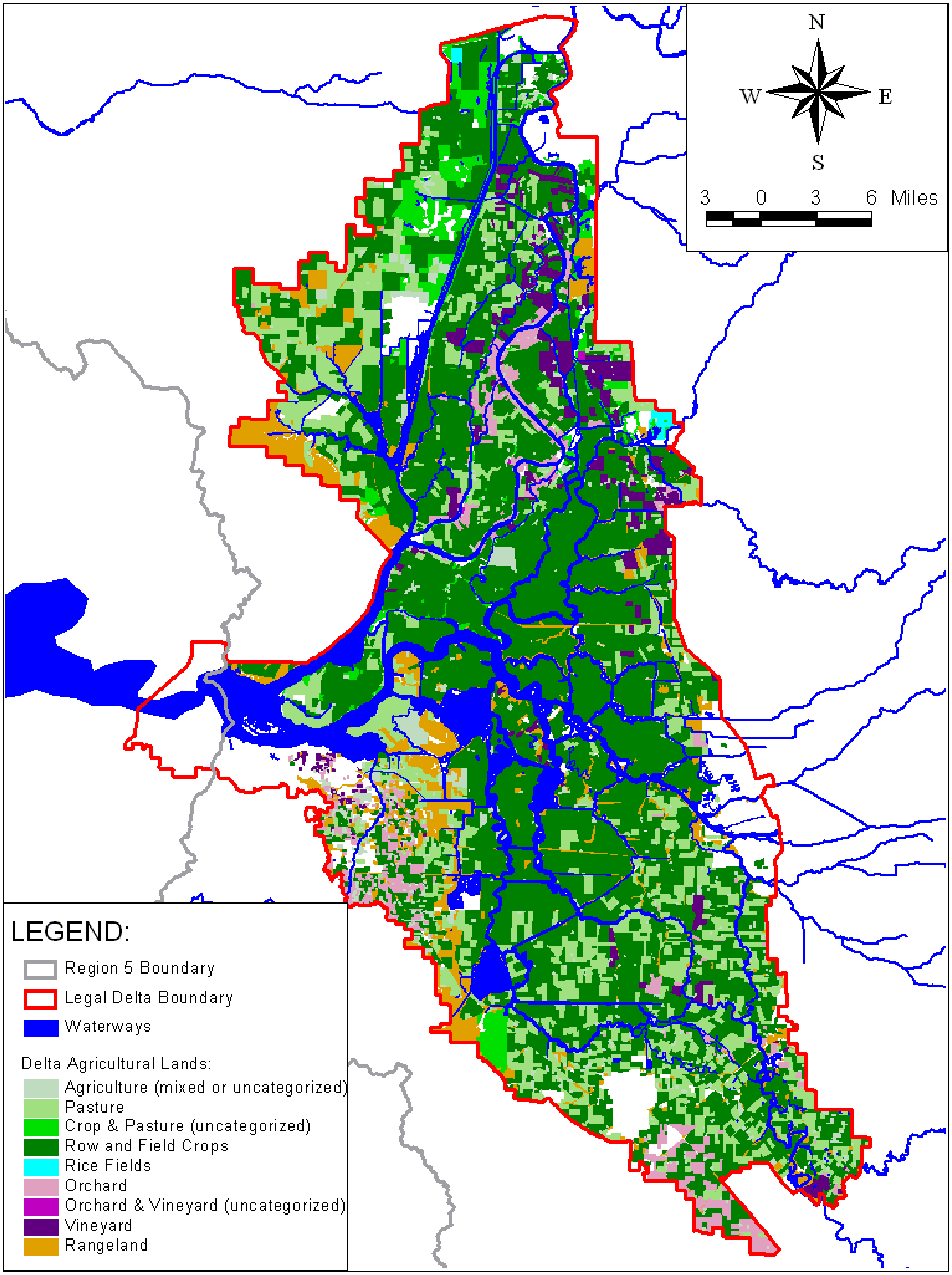

Figure 6.6: Agricultural Lands within the Statutory Delta Boundary.
(Agricultural land uses outside the Delta are not shown.)

Table 6.6: Values Used to Estimate MeHg Loads from Agricultural Lands

	Average MeHg Conc. (ng/l) (a)	**Flow** (af/yr) (b)	**MeHg Load** (g/yr)
Diversions:	0.071	1,597,880	139
Ag Drain Returns:	0.352	603,546	262
Net Ag Drain Input (g/yr):			**123**

(a) Average agricultural drain methylmercury concentration obtained from Table 6.7. Average methylmercury concentration for diversion flows was estimated by averaging monthly Sacramento River and State Water Project MeHg concentrations during May through December (Appendix D).
(b) Estimated annual average agricultural diversion and return flows were obtained from Table 6.6.

Table 6.7: Delta Agricultural Main Drain Methylmercury Concentration Data (a)

Site	**Sample Date**	**MeHg Conc. (ng/l)**
Empire Tract Main Drain	6/26/00	0.093
Empire Tract Main Drain	7/19/00	0.117
Lower Jones Main Drain	6/26/00	0.302
Staten Island Main drain	6/26/00	0.198
Staten Island Main drain	7/19/00	0.094
Twitchell Island Main Drain	6/26/00	0.387
Twitchell Island Main Drain	7/19/00	1.500
Twitchell Island Main Drain	6/30/03	0.292 (b)
Twitchell Island Main Drain	7/28/03	0.341
Twitchell Island Main Drain	8/27/03	0.609
Twitchell Island Main Drain	9/25/03	0.157 (b)
Upper Jones Main Drain	7/19/00	0.131

(a) Source: Foe, 2003; Central Valley Water Board sampling, 2003.
(b) Average of laboratory replicates (0.289 and 0.294 ng/l on 6/30/03 and 0.147 and 0.167 ng/l on 9/25/03).

Table 6.8: Delta-wide Island Consumptive Use Estimates - Water Year 1999 (acre-feet) (a)

Period	Diversions + Seepage	Return Flow	Net Channel Depletion
Oct-98	92,969	36,155	56,815
Nov-98	74,202	34,988	39,213
Dec-98	81,348	31,359	49,989
Jan-99 (b)	*42,180*	*111,661*	*-69,481*
Feb-99 (b)	*34,044*	*120,960*	*-86,916*
Mar-99	57,306	43,410	13,896
Apr-99	108,000	46,532	61,468
May-99	193,317	67,944	125,373
Jun-99	273,838	92,648	181,190
Jul-99	353,800	120,147	233,653
Aug-99	221,540	77,167	144,373
Sep-99	141,560	53,197	88,364
Annual Totals (b)	**1,597,880**	**603,546**	**994,334**

(a) Diversion and flow volumes were obtained from the Delta Island Consumptive Use Model (Suits, 2000).
(b) Only months with positive depletion were used in the annual methylmercury load estimates because during Jan-Feb there is (1) substantial return flow resulting from rainfall, which is assumed to contain no methylmercury, and (2) no methylmercury concentration data were available for the agricultural return drains during the coolest/wettest months.

Table 6.9: Agricultural Acreage and Methylmercury Load Estimates by Delta Subarea

	Central Delta	Cosumnes / Mokelumne River	Marsh Creek	Sacramento River	San Joaquin River	West Delta	Yolo Bypass-North	Yolo Bypass-South	**TOTAL**
Acreage (a)	157,035	6,790	9,362	155,532	96,874	17,313	11,046	70,523	**524,474**
% of Total Acreage	30%	1.3%	1.8%	30%	18%	3.3%	2.1%	13%	**100%**
Estimated Annual MeHg Load (g/year) (b)	36.8	1.6	2.2	36.4	22.7	4.1	2.6	16.5	**123**

(a) Land cover source: DWR land use GIS coverages (1993-2003).
(b) A Delta-wide agricultural land methylmercury loading of 123 g/yr was estimated using the information presented in Tables 6.6 through 6.8. The Delta-wide load was multiplied by the percentage of total agricultural acreage located in each Delta subarea to estimate the amount of loading from agricultural lands in each subarea.

6.2.5 Urban Runoff

Approximately 60,000 acres of the land in the Delta is classified as urban (DWR, 1993-2003). Most of the urban area is regulated by waste discharge requirements under the National Pollutant Discharge Elimination System (NPDES), which permits discharge of storm water from municipal separate storm sewer systems (MS4s).[35] Table 6.10 lists the permits that regulate urban runoff in the Delta and the amount of urban acreage in each Delta subarea. Figure 6.7 shows their locations. Urban acreages corresponding to each Permittee were estimated from the DWR Land Use coverage (DWR, 1993-2003) using available MS4 service area delineations. MS4 service area delineations for Sacramento, Stockton and Tracy are based on paper or electronic maps provided by the MS4 Permittees; all other MS4 service areas were delineated using 1990 city and county boundaries. Urban areas not encompassed by a MS4 service area were grouped into a “nonpoint source” category within each Delta subarea.

Methylmercury concentration data have been collected by Central Valley Water Board staff and the City and County of Sacramento from several urban waterways in or adjacent to the Delta. Figure 6.8 shows the sampling locations and Figure I.1 in Appendix I illustrates the wet and dry weather concentrations by location. Methylmercury concentrations ranged from a wet weather low of 0.035 ng/l (City of Sacramento Sump 111) to a dry weather high of 2.04 ng/l (Strong Ranch Slough). A visual inspection of the methylmercury data suggests that the differences between urban watersheds are not related to land use. Therefore, the data were averaged by wet and dry weather for each location (Table 6.11). The

[35] A municipal separate storm sewer system (MS4) is a conveyance or system of conveyances that include roads with drainage systems, municipal streets, alleys, catch basins, curbs, gutters, ditches, manmade channels, or storm drains, owned by a State, city, county, town or other public body. MS4s are designed and used for collecting or conveying storm water and do not include combined sewer systems or parts of a publicly owned treatment works. MS4s discharge to Waters of the United States. The Municipal Storm Water Permitting Program regulates storm water discharges from MS4s. MS4 permits were issued in two phases. Under Phase I, which started in 1990, the RWQCBs have adopted NPDES storm water permits for medium (serving between 100,000 and 250,000 people) and large (serving greater than 250,000 people) municipalities. Most of these permits are issued to a group of co-permitees encompassing an entire metropolitan area. These permits are reissued as the permits expire. As part of Phase II, the State Board adopted a General Permit for the discharge of storm water from small MS4s (WQ Order No. 2003-0005-DWQ, NPDES No. CAS000004) to provide permit coverage for smaller municipalities, including non-traditional small MS4s, which are governmental facilities such as military bases, public campuses, and prison and hospital complexes.

averages of these location-based wet and dry weather averages are assumed to represent runoff from all urban areas in or adjacent to the Delta and were used to estimate loads. These values are similar to methylmercury levels observed during high flow conditions in two urbanized tributaries in the Washington, D.C. region. The urbanized Northeast and Northwest Branches of the Anacostia River had average methylmercury concentrations of 0.12 ± 0.06 ng/l and 0.07 ± 0.07 ng/l, respectively, during base flows, and 0.39 ± 0.21 ng/l and 0.77 ± 0.46 ng/l, during high flows (Mason & Sullivan, 1998).

Average annual urban runoff loading was estimated for WY2000-2003 so that urban runoff loading could be compared to tributary loading (Table 6.2). To estimate wet weather methylmercury loads, the wet weather concentration (0.241 ng/l) was multiplied by the runoff volumes estimated for WY2000-2003 for each MS4 area within each Delta subarea. To estimate dry weather methylmercury loads, the dry weather concentration (0.363 ng/l) was multiplied by the estimated dry weather urban runoff volume. Section E.2.3 in Appendix E describes the methods used to estimate wet and dry weather runoff volumes from urban areas within the Delta. Wet and dry weather methylmercury loads were summed to estimate the average annual loading of 21 grams to Delta waterways. The loading to each Delta subarea (Table 6.12) was used to develop MS4 Permittee and subarea-specific allocations (Chapter 8).

Table 6.10: MS4 Permits that Regulate Urban Runoff within the Delta

Permittee	NPDES # (a)	Urban Acreage within Delta Subareas (b)							Total Acreage
		Central Delta	Cosumnes/ Mokelumne River	Marsh Creek	Sacramento River	San Joaquin River	West Delta	Yolo Bypass	
City of Lathrop	CAS000004					738			**738**
City of Lodi	CAS000004	134							**134**
City of Rio Vista	CAS000004				38				**38**
City of Tracy	CAS000004					5,268			**5,268**
City of West Sacramento	CAS000004				1,715			2,754	**4,470**
County of Contra Costa	CAS083313	2,181		3,427			9,528		**15,135**
County of San Joaquin	CAS000004	1,494	134		521	7,140			**9,288**
County of Solano	CAS000004				184			220	**404**
County of Yolo	CAS000004				200			273	**473**
Port of Stockton MS4	CAS084077	1,067				28			**1,095**
Sacramento Area MS4 (c)	CAS082597				7,975				**7,975**
Stockton Area MS4	CAS083470	10,574				1,481			**12,055**
Urban Nonpoint Source (d)		337	42		1,620	7	65		**2,070**
Total Acreage		**15,786**	**176**	**3,427**	**12,253**	**14,663**	**9,592**	**3,247**	**59,144**

(a) Permittees with NPDES No. CAS000004 are covered under the General Permit for the discharge of storm water from small MS4s (WQ Order No. 2003-0005-DWQ) adopted by the State Board to provide permit coverage for smaller municipalities (serving less than 100,000 people).
(b) Urban land uses and acreages corresponding to each Permittee were estimated from the DWR Land Use coverage (DWR, 1993-2003) using available service area delineations. MS4 service area delineations for Sacramento, Stockton and Tracy are based on paper or electronic maps provided by the MS4 Permittees; all other MS4 service areas were delineated using 1990 city boundaries.
(c) The Sacramento MS4 Area does not include the Sacramento Combined Sewer System (CSS) service area illustrated in Figure 6.7. The CSS service area is permitted by a separate NPDES permit, which is described in Section 6.2.3 and TableG.2 in Appendix G.
(d) Urban areas not encompassed by a MS4 service area were grouped into the “nonpoint source” category.

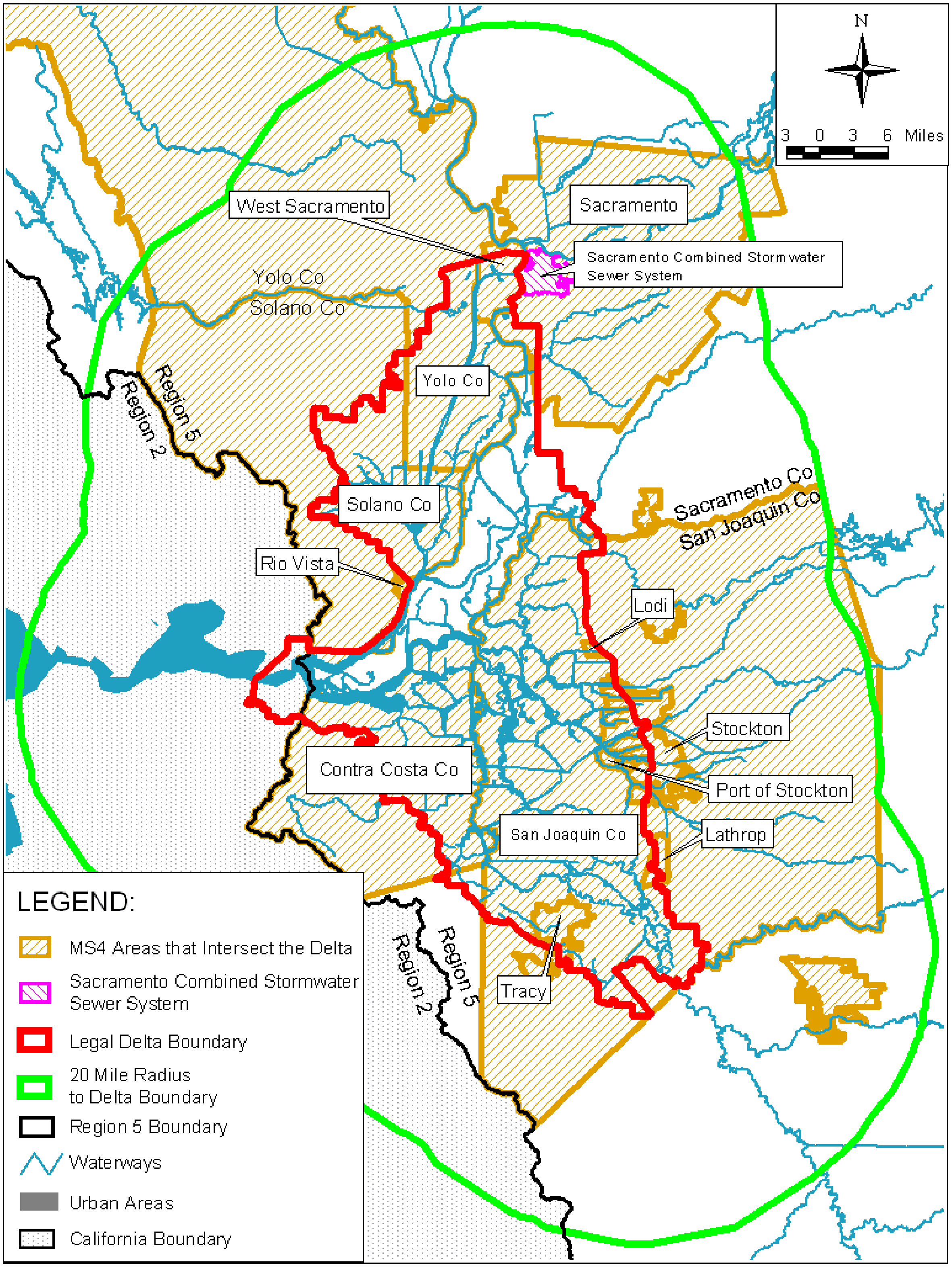

Figure 6.7: NPDES Permitted Municipal Separate Storm Sewer System (MS4) Areas in the Delta Region (Only those MS4 areas that intersect the statutory Delta boundary are labeled. MS4 service area delineations for Sacramento, Stockton and Tracy are based on paper or electronic maps provided by the MS4 Permittees; all other MS4 service areas were delineated using 1990 city or county boundaries.)

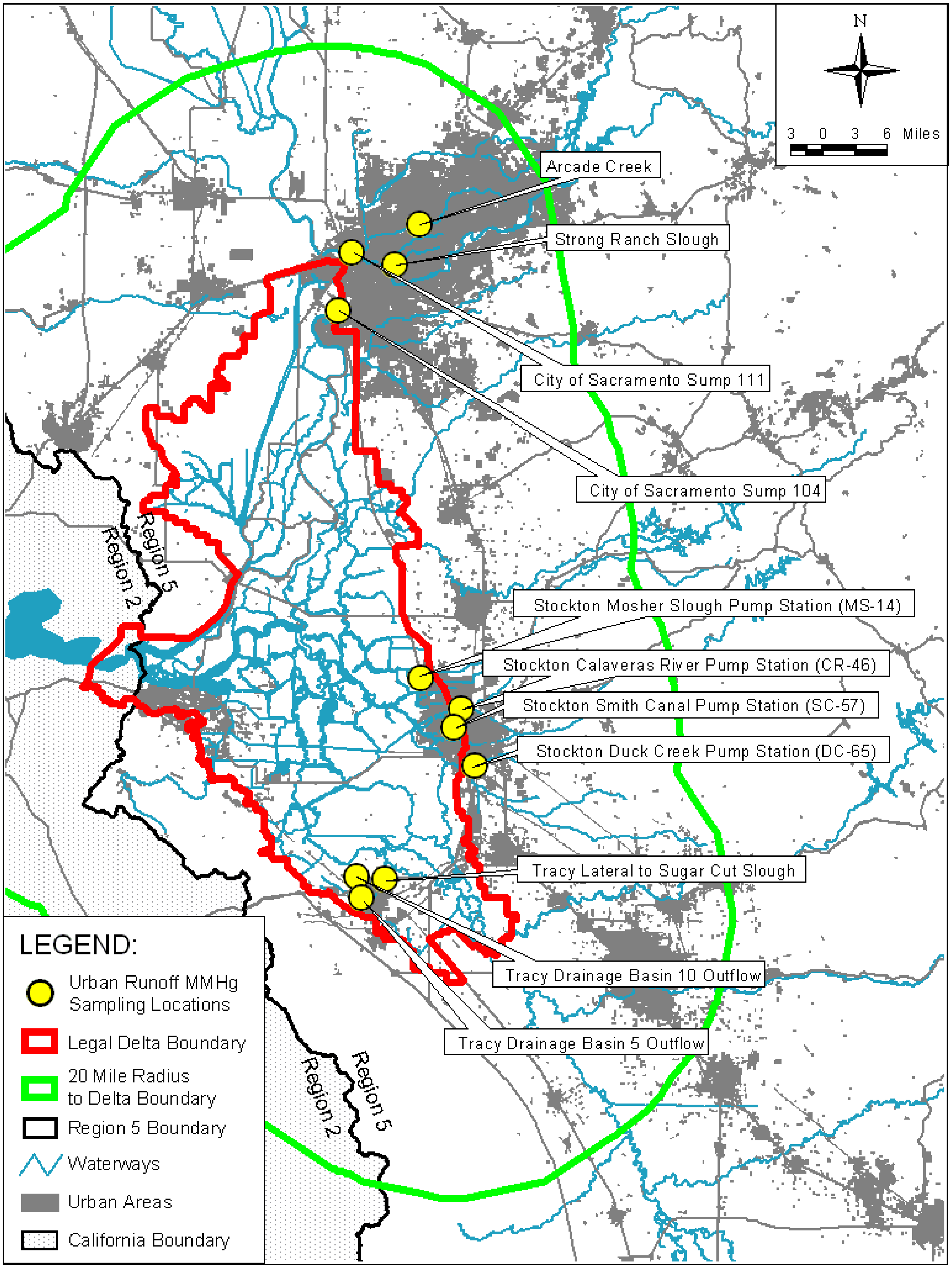

Figure 6.8: Urban Areas and Aqueous MeHg Sampling Locations in the Delta Region

Table 6.11: Summary of Urban Runoff Methylmercury Concentrations

Location	# of Samples	Minimum Conc. (ng/l)	Average Conc. (ng/l)	Maximum Conc. (ng/l)
DRY WEATHER				
Arcade Creek	9	0.099	0.358	1.213
Sacramento Strong Ranch Slough	2	0.158	1.099	2.040
Sacramento Sump 104	2	0.088	0.093	0.097
Sacramento Sump 111	2	0.135	0.176	0.217
Tracy Lateral to Sugar Cut Slough	1	0.091	0.091	0.091
Average of Location Averages:	**0.363 ng/l**			
WET WEATHER				
Arcade Creek	7	0.099	0.240	0.339
Sacramento Strong Ranch Slough	4	0.237	0.522	0.878
Sump 104	4	0.153	0.290	0.610
Sump 111	4	0.035	0.212	0.420
Stockton Calaveras River Pump Station	5	0.105	0.167	0.301
Stockton Duck Creek Pump Station	1	0.103	0.103	0.103
Stockton Mosher Slough Pump Station	4	0.084	0.125	0.189
Stockton Smith Canal Pump Station	4	0.099	0.263	0.533
Tracy Drainage Basin 10 Outflow	3	0.103	0.192	0.257
Tracy Drainage Basin 5 Outflow	3	0.110	0.138	0.191
Tracy Lateral to Sugar Cut Slough	3	0.040	0.400	0.918
Average of Location Averages:	**0.241 ng/l**			

Table 6.12: Average Annual Methylmercury Loading from Urban Areas within Each Delta Subarea for WY2000-2003

MS4 PERMITEE	DELTA SUBAREA							Grand Total
	Central Delta	Cosumnes / Mokelumne River	Marsh Creek	Sacramento River	San Joaquin River	West Delta	Yolo Bypass	
City of Lathrop					0.27			0.27
City of Lodi	0.053							0.053
City of Rio Vista				0.014				0.014
City of Tracy					1.83			1.83
City of West Sacramento				0.62			1.09	1.71
County of Contra Costa	0.75		1.16			3.25		5.16
County of San Joaquin	0.57	0.051		0.19	2.62			3.43
County of Solano				0.074			0.085	0.16
County of Yolo				0.073			0.12	0.19
Port of Stockton MS4	0.39				0.010			0.40
Sacramento Area MS4				2.96				2.96
Stockton Area MS4	3.57				0.50			4.07
Urban Nonpoint Source	0.13	0.018		0.63	0.0022	0.024		0.81

Grand Total	5.47	0.068	1.16	4.56	5.22	3.28	1.30	21.1

Urban land use comprises a small portion of the surface area in the Delta and contributes only about 0.4% of the Delta methylmercury load (Table 6.2). In contrast, approximately 320,000 acres of urban land – about 42% of all urban area within the Delta source region – occur within 20 miles of the statutory Delta boundary, about one day water travel time upstream. In addition, some of the urban watersheds outside the Delta discharge via sumps into Delta waterways. These discharges were not included in the Delta load estimate. As a result, the urban contribution to the Delta methylmercury load may be underestimated.

To evaluate the potential contributions from upstream urban lands, the methylmercury loadings from the two MS4 service areas with the greatest urban acreage immediately outside the Delta were estimated. The sum of methylmercury loads from the Sacramento and Stockton MS4 areas may contribute more than 1% of methylmercury loading to the Delta (Table 6.13). These loads are expected to increase as urbanization continues around the Delta.

Table 6.13: Comparison of Sacramento & Stockton Area MS4 Methylmercury Loading to Delta Methylmercury Loading (a)

MS4 Service Area (Urban Acreage)	**Water Volume** (acre-feet) (b)	**MeHg Load** (grams/year)
Sacramento MS4 Urban Total	174,593	51
Stockton MS4 Urban Total	25,304	7.4
Total Delta Inputs (c)	19,425,472	4,933
Stockton & Sacramento Runoff as % of Total Delta Inputs	**1.0%**	**1.3%**

(a) The Sacramento and Stockton Area MS4s are the two MS4 service areas with the greatest urban acreage immediately outside the Delta, with urban land use areas 154,050 and 24,901acres, respectively.
(b) Refer to Section E.2.3 in Appendix E for urban runoff volume estimates for wet and dry weather, which were summed to estimate the annual average water volumes shown above.
(c) These values represent the sum of all tributary and within-Delta methylmercury sources shown in Table 6.2.

6.2.6 Atmospheric Deposition

Atmospheric deposition of methylmercury has not yet been measured within the Delta. However, several published papers provide reviews of methylmercury levels in wet deposition in a variety of locations around the world (e.g., Nguyen *et al.*, 2005; Lawson & Mason, 2001; Mason *et al.*, 1997 & 2000). These reviews indicate that the ratios of methyl to total mercury concentrations in wet deposition range from 0.25 to 6%, and that typically less than 1% of total mercury in wet deposition is methylmercury. As described in Section 7.1.4 and Table 7.1, total mercury loading from wet deposition to Delta water surfaces (direct deposition) was estimated to be 0.853 kg/yr (853 g/yr). A methyl to total mercury ratio of 1% was used to estimate the mass of methylmercury deposited by direct wet deposition:

Equation 6.2:

$$\text{MeHg Mass} = \text{Total mercury mass} * \text{MeHg:TotHg}$$
$$8.5 \text{ g/yr} = 853 \text{ g/year} * 0.01$$

Table 6.14 provides the methylmercury load estimates for direct deposition to waterways in each Delta subarea. Wet deposition to Delta waterways likely contributes less than 0.2% of all methylmercury entering the Delta (Table 6.2). Therefore, it is assumed that direct atmospheric input to Delta water surfaces is not a significant source of methylmercury. Methylmercury in wet deposition to land surfaces was not evaluated because it is incorporated in the estimates for loading from agricultural and urbanized lands described in Sections 6.2.4 and 6.2.5. Agricultural and urban areas comprise the majority of land surfaces in the Delta.

Table 6.14: Estimate of Direct Wet Deposition of Methylmercury to Delta Waterways

Delta Subarea	**Rainfall on Waterways** (acre-feet/yr) (a)	**WY2000-2003 Average Annual TotHg Load** (g/yr) (a)	**Estimated MeHg Load** (g/yr) (b)
Central Delta	35,127	321	3.2
Cosumnes / Mokelumne River	262	2.4	0.024
Marsh Creek	5	0.049	0.0005
Sacramento River	16,536	151	1.5
San Joaquin River	4,482	41	0.41
West Delta	25,102	229	2.3
Yolo Bypass-North	2,130	19	0.19
Yolo Bypass-South	9,853	90	0.90
TOTAL	**93,498**	**853**	**8.5**

(a) Total mercury loading from precipitation on surface water in the Delta (direct deposition) was estimated by multiplying the average mercury concentration in North Bay/Martinez rainwater (Section 7.1.4, Table 7.10) by the average rainfall volume to fall on Delta water surfaces during WY2000-2003 (Section E.2.3 in Appendix E).

(b) The published literature indicates that ratios of methyl to total mercury concentrations in wet deposition typically range from 0.25% to 6%, and that typically less than 1% of total mercury in wet deposition is methylmercury. A methyl to total mercury ratio of 1% was used to estimate the mass of methylmercury deposited to waterways in each subarea.

6.3 Methylmercury Losses

The following were identified as contributing to methylmercury losses from the Delta: water exports to southern California, outflow to San Francisco Bay, removal of dredged sediments, photodegradation, biotic uptake and unknown loss term(s). Table 6.15 lists the average methylmercury concentrations and estimated average annual loads associated with the losses for the WY2000-2003 period, a relatively dry period that encompasses the available concentration data for the major Delta inputs and exports. Figure 6.9 shows the aqueous monitoring locations for major methylmercury exports and the approximate locations of recent dredging projects.

Table 6.15: Methylmercury Concentrations and Loads Lost from the Delta for WY2000-2003.

	Average Annual Load (g/yr)	**% All MeHg**	**Average Aqueous Concentration** (ng/l)
Outflow to San Francisco Bay (X2)	1,717	70%	0.08
Dredging	341	13.8%	- - -
State Water Project	203	8.2%	0.05
Delta Mendota Canal	201	8.2%	0.06
Photodegradation	*To Be Determined*		
Accumulation in Biota	*Unknown*		
TOTAL EXPORTS:	**2,462 g/yr (2.5 kg/yr)**		

6.3.1 *Outflow to San Francisco Bay*

Outflow to San Francisco Bay is the primary way that methylmercury is lost from the Delta. Methylmercury in Delta outflow to San Francisco was evaluated by collecting samples at X2. X2 is the location in the Bay-Delta Estuary with 2 o/oo bottom salinity. The location of X2 moves as a function of both tidal cycle and freshwater inflow, typically between the Cities of Martinez and Pittsburg, west of the legal Delta boundary. This salinity was chosen because 2 to 3 o/oo salinity is the normal osmotic tolerance of freshwater organisms, and a goal of the CALFED studies was to estimate the methylmercury exposure of these organisms.

Staff from the Central Valley and San Francisco Bay Central Valley Water Boards has agreed to consider Mallard Island as the boundary between the two regions for control of mercury. The site was selected as it is near the legal boundary and has a U.S. Geological Survey flow gauge. Central Valley Water Board staff has begun collecting methylmercury concentration data at Mallard Island and will use this to better estimate advective and dispersive flux of methylmercury from the Central Valley to San Francisco Bay. The data will be collated and a report prepared in the fall of 2006.

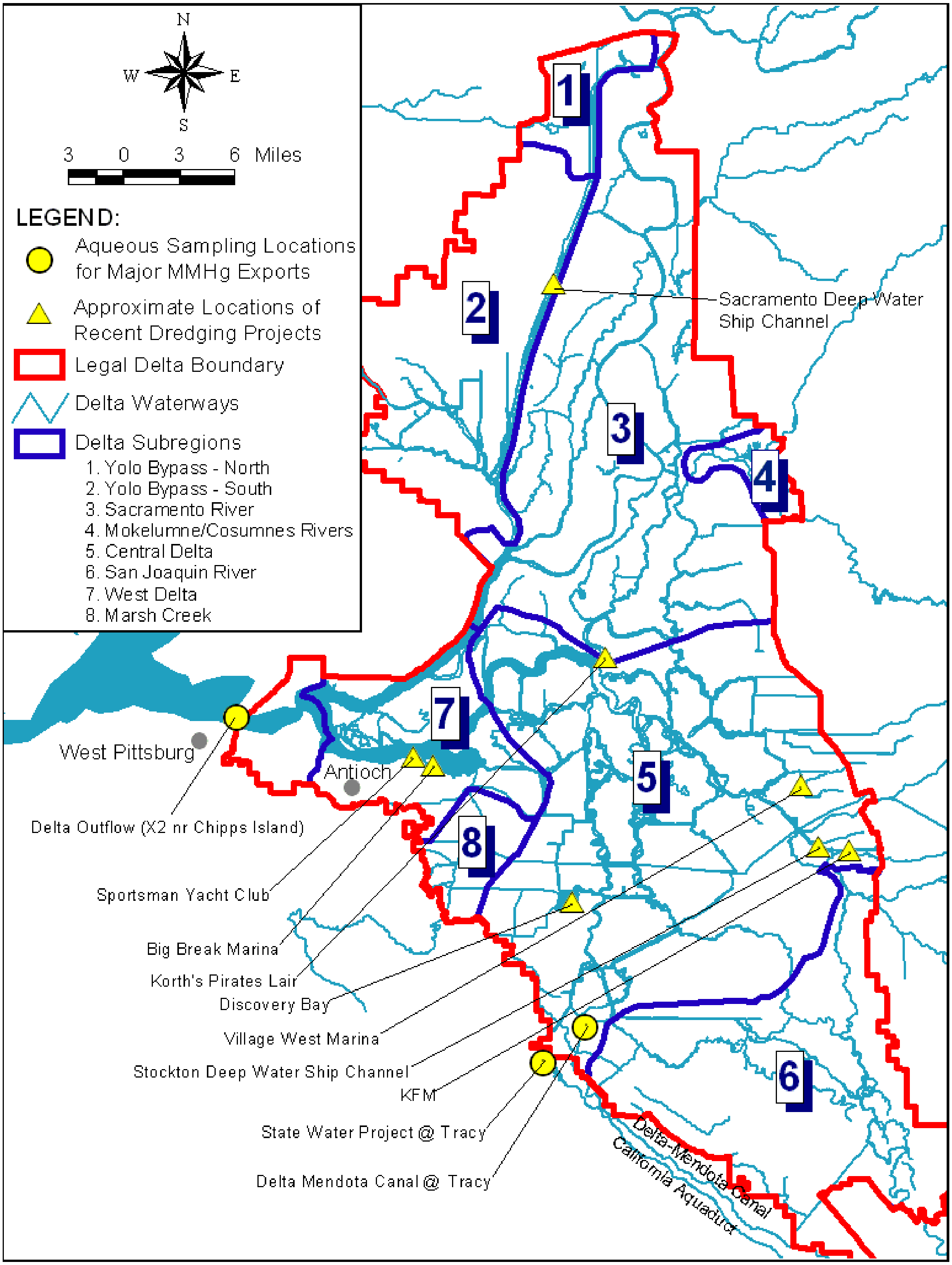

Figure 6.9: Aqueous Monitoring Locations for Major MeHg Exports and Approximate Locations of Recent Dredging Projects.

Central Valley Water Board staff conducted monthly aqueous methylmercury sampling at X2 from March 2000 to September 2001 (Foe, 2003) and from April to September 2003. Figure 6.10 and Table 6.16 summarize the export data. Methylmercury concentrations at X2 averaged 0.075 ng/l and ranged from below detection limits to 0.241 ng/l. Net daily Delta outflow water volumes were obtained from the Dayflow model (Section E.2.4 in Appendix E). Methylmercury concentrations for X2 and net daily Delta outflows were regressed against each other to determine whether flow could be used to predict methylmercury concentration (Appendix F). The regression was significant at $P<0.05$ and accounted for about 20% of the variation in methylmercury concentrations. The regression-based export loads was 2,086 g/yr (Appendix F).

An alternate approach is to use average monthly methylmercury concentrations to estimate Delta exports. Concentration data were pooled by month to calculate monthly average concentrations for WY2000-2003 (Tables D.1 and D.2 in Appendix D). Monthly average concentrations were multiplied by monthly average flows for WY2000-2003 to estimate monthly loads and summed to calculate an annual average methylmercury load for WY2000-2003 of 1,717 g/yr. The latter estimate appears similar to the regression-based estimate (2,086 g/yr). Table 6.15 uses an advective export rate of 1,717 g/yr to San Francisco Bay. This accounts for approximately 70% of Delta methylmercury losses. No attempt was made to estimate dispersive loads. It is not known whether dispersive or tidal flows would increase or decrease the net methylmercury load exported to the Bay area.

6.3.2 South of Delta Exports

Water diversions to southern California account for approximately 16% of Delta methylmercury losses (Table 6.15). Methylmercury in Delta Mendota Canal (DMC) and State Water Project (SWP) exports to southern California were evaluated by collecting water samples from the DMC canal off Byron Highway (County Road J4) and from the input canal to Bethany Reservoir, respectively. Bethany is the first lift station on the State Water Project canal system and is about one mile south of Clifton Court Forebay in the Delta. Figure 6.9 illustrates the sampling locations.

Central Valley Water Board staff conducted monthly methylmercury sampling at the DMC and SWP from March 2000 to September 2001 (Foe, 2003) and from April 2003 to April 2004. Figure 6.10 and Table 6.16 summarize methylmercury concentrations. The volume of water exported by the DMC and SWP was obtained from the Dayflow model (Section E.2.4 in Appendix E). Like at X2, methylmercury concentrations were regressed against daily flow to determine whether the concentrations could be predicted from the flow (Appendix F). Neither regression was significant ($P<0.05$). Therefore, average methylmercury concentrations were used to estimate SWP and DMC export loads of 203 and 201 g/yr (Table 6.15). Additional methylmercury data is being collected at both pumping sites to better characterize methylmercury loads. This data should be available in an interpretive report in the winter of 2006.

6.3.3 Export via Dredging

Sediment is dredged at various locations in the Delta to maintain ship channels and marinas. No data have been gathered on methylmercury levels in dredge material removed from the Delta. To determine whether dredging activities could result in notable methylmercury loss from the Delta, a preliminary load

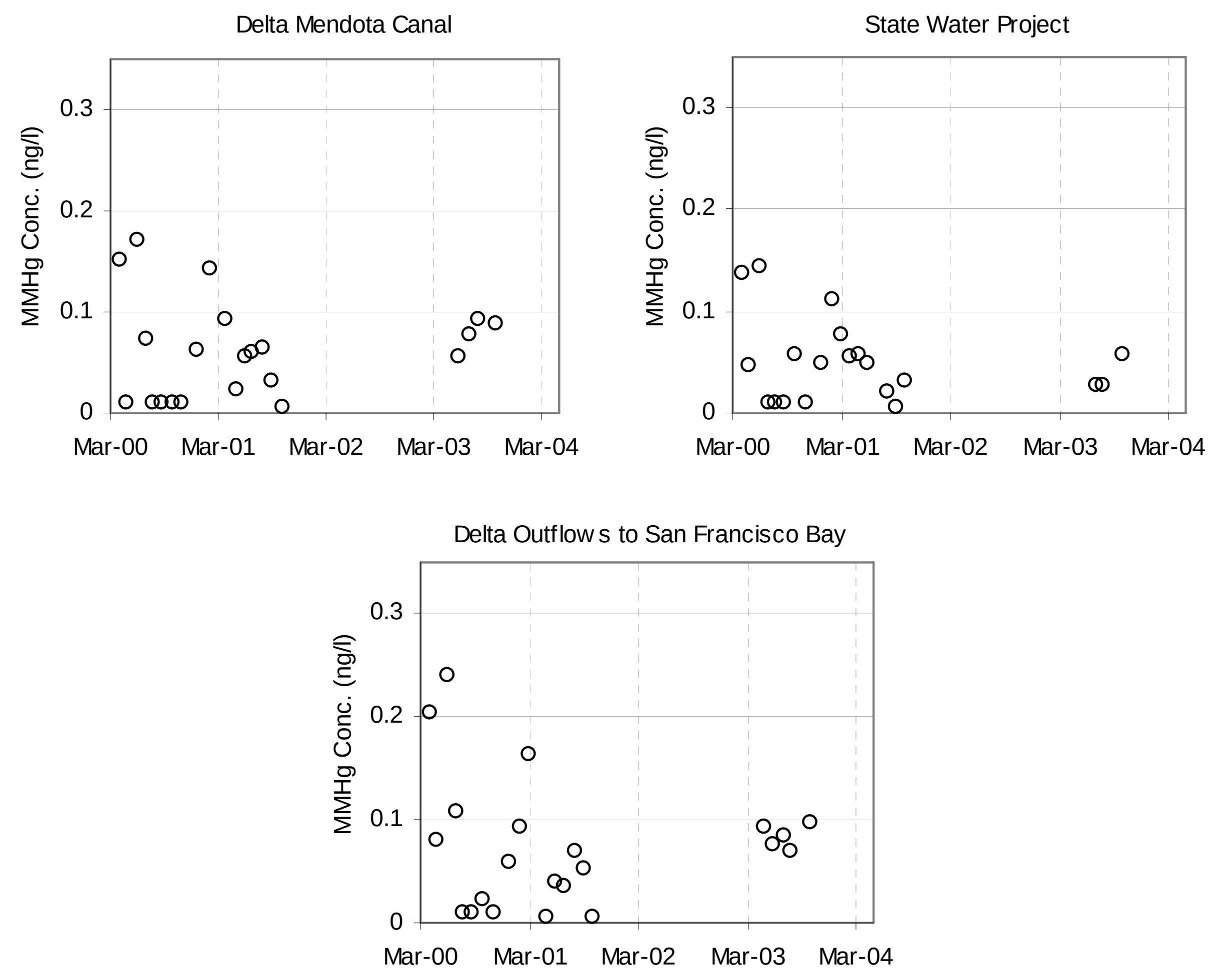

Figure 6.10: Available Methylmercury Concentration Data for the Delta's Major Exports

Table 6.16: Methylmercury Concentrations for the Delta's Major Exports

Site	# of Samples	Min. MeHg Conc. (ng/l) (a)	Ave. MeHg Conc. (ng/l)	Annual Ave. Conc. (ng/l) (b)	Median MeHg Conc. (ng/l)	Max. MeHg Conc. (ng/l)
Delta Mendota Canal	21	ND	0.062	0.064	0.061	0.171
State Water Project	20	ND	0.064	0.054	0.050	0.291
Outflow to San Francisco Bay (X2)	22	ND	0.075	0.083	0.070	0.241

(a) ND: below method detection limit.
(b) Sampling of these exports took place between March 2000 and September 2003. Methylmercury concentration data were pooled by month to estimate monthly average methylmercury concentrations and loads (Tables D.1 and D.2); the monthly average loads were summed to estimate annual average methylmercury loads for water years 2000-2003. The monthly average concentrations were averaged to estimate annual average concentrations, which were included in Table 6.15.

estimate was developed using available dredge volume and total mercury information and surficial sediment methylmercury concentration data. Methylmercury removed by dredge activities could account for almost 14% of the identified methylmercury exports from the Delta (Table 6.15).

Dredge material is typically pumped to either disposal ponds on Delta islands or upland areas with monitored return flow. Table 6.18 provides details on recent dredge projects within the Delta and Figure 6.9 shows their approximate locations. The Sacramento and Stockton deep water channels have annual dredging programs; the locations dredged each year vary. Dredging occurs at other Delta locations when needed, when funds are available, or when special projects take place. Approximately 533,400 cubic yards of sediment are dredged annually on average, with 199,000 cubic yards from the Sacramento Deep Water Ship Channel and 270,000 cubic yards from the Stockton Deep Water Channel. Other minor dredging projects at marinas remove sediment at various frequencies for a combined total of about 64,400 cubic yards per year. Average mercury concentrations in the sediment for the project sites range from 0.04 to 0.44 mg/kg (dry weight). The annual mass of mercury removed from the Delta through dredging projects is approximately 57 kg/year. Section 7.2.3 provides a description of the methods used to estimate the annual mass of total mercury removed by dredging and the uncertainty in the estimate. None of the dredging projects analyzed sediment samples for methylmercury. Heim and others (2003) evaluated surficial sediment MeHg:TotHg at several locations in the Sacramento and Stockton Deep Water Channels (Table 6.17), where nearly 90% of all dredged materials from the Delta are removed. The average MeHg:TotHg of 0.006 was used to estimate the mass of methylmercury removed by dredging projects:

Equation 6.3:

$$\text{MeHg Mass} = \text{Total mercury mass} * \text{MeHg:TotHg}$$
$$341 \text{ g/yr} = 57 \text{ kg/year} * 1000 \text{ (g/kg)} * 0.006$$

Use of surficial sediment MeHg:TotHg to estimate methylmercury mass removed by dredging assumes that MeHg:TotHg is consistent throughout all depths of sediment in the dredged areas, which may overestimate the mass removed if MeHg levels actually decrease with depth. In addition, methylmercury production may increase after dredging activities if the newly exposed sediment has higher total mercury concentrations. Central Valley Water Board staff recommends that dredgers quantify the amount of methylmercury removed and that the mercury concentration of fine grain material in newly exposed sediment be assayed (see Chapter 4 in the Proposed Basin Plan Amendment draft staff report).

Table 6.17: MeHg:TotHg in Deep Water Ship Channel Surficial Sediments

	MeHg Conc. (ng/g)	**TotHg Conc.** (ng/g)	**MeHg:TotHg Ratio**
Sacramento Deep Water Ship Channel			
Sacramento River DWSC	0.49	194.70	0.0025
Stockton Deep Water Channel			
Little Connection Slough	0.20	82.51	0.0024
Headreach Cutoff	1.86	89.46	0.0208
Port of Stockton Turnabout #1	0.32	193.78	0.0017
Port of Stockton Turnabout #2	0.32	130.30	0.0025
		AVERAGE RATIO:	**0.006**

(a) Source: Heim *et al.*, 2003. Latitude/longitude coordinates provided with the above samples indicated that these were collected within the dredged deep water ship channels.

Table 6.18: Recent Dredge Projects within the Delta.

Delta Dredging Project	Project Location	Volume of Dredge Material (cubic yards)	Dredge Frequency	Disposal Location (upland, Delta island, wetland areas, etc.)	Mean Sediment Mercury Conc. (mg/kg, dry wt) (a)	# of Samples	Standard Dev.	t Value (p=0.975, conf 95%, df =n-1)	Total Weight of Mercury Removed (kg)	Annual Weight of Mercury Removed (a) (kg)	Annual Weight of Sediment Removed (Mkg, dry wt)	Annual Volume of Water Removed (acre-feet)	Does Effluent Return to a Receiving Water?	Average Effluent Hg Conc. (μg/l)
Sac. River Deep Water Ship Channel (b)	Sacramento River	199,000	Annually	Delta Island/ upland	0.37 ±3.93	2	0.4377	12.71	42	42 ±446 (n)	110.5	89.6	No	0.05 to 0.1
Stockton Deep Water Channel (c)	San Joaquin River	270,000	Annually	Delta Islands	0.083 ±0.023	28	0.0594	2.052	13	13 ±3.5	150.0	121.5	No	0.05 to 0.13
Village West Marina (d)	14-Mile Slough	70,000	Every 10 years	Delta Islands	0.043 ±0.014	3	0.0058	4.303	1.7	0.2 ±0.057	3.9	3.2	Yes (l)	0.05
KFM (e)	San Joaquin River	3,000	One time	Upland	*Unknown*						1.7	1.4	No	0.05
Korths Pirates Lair (f)	Mokelumne River	15,000	Every 5 years	Upland	0.15 ±0.11	2	0.0120	12.71	1.3	0.25 ±0.18	1.7	1.4	No	0.05
Big Break Marina (g)	San Joaquin River	12,000	Every 5 years	Upland	0.41 ±0.24	6	0.2318	2.571	2.8	0.55 ±0.33	1.3	1.1	No	0.25
Sportsman Yacht Club (h)	San Joaquin River	10,000	Every 5 years	Upland	0.12 ±0.014	3	0.0058	4.303	0.70	0.14 ±0.016	1.1	0.9	No	0.05
Discovery Bay (i)	Delta	50,000 (j)	Annually	Upland	0.027 ±0.018	7	0.0195	2.447	0.78	0.78 ±0.51	27.8	22.5	Yes (k, l)	0.05
Annual Averages (m)		**533,400 cubic yards**								**57 ±451 kg** (n)	**349 Mkg**	**283 a-ft**		

(a) The uncertainty of the mercury load values was estimated by calculating the 95% confidence interval for the mean of the concentration data for each project.
(b) U.S. Army Corps of Engineers, 2002 NOI (Notice of Intent) Sacramento DWSC.
(c) U.S. Army Corps of Engineers, 2000-2003 NOI Stockton DWSC.
(d) DCC Engineering Co, Inc., Village West Dredge Material Test, September 5, 2000.
(e) KFM, 401 Water Quality Certification.
(f) Anderson Engineers, 2003 Sediment Sampling and Analysis Plan for Korths Pirates Lair.
(g) Subsurface Consultants, Inc., Environmental Site Assessment 2001 & Aquifer Sciences, Inc., Pre-Dredge Sampling and Analysis Plan July 29, 2003.
(h) Padre Associates, Inc., Laboratory Analytical Results of Proposed Dredge Material and Associated Waste Classification May 23, 2003.
(i) Kennetic Laboratories/ToxScan, Inc., Sediment Properties and Chemistry April 2002, Discovery Bay, 2003 Final Water Quality Monitoring Report, WDR Order No. R5-2003-0027.
(j) Discovery Bay assumptions: The initial dredge project was 153,000 cubic yards, and 50,000 cubic yards/year thereafter. Therefore, assume 50,000 cy/year.
(k) WDR Order N. R5-2003-0027 indicates effluent returned to Discovery Bay averaged 3 mgd for several days to several weeks; staff assumed discharge period is 14 days/year.
(l) Two dredging projects, Village West Marina and Discovery Bay, had effluent that returned to Delta waters. The volume of effluent returned to receiving waters by the Discovery Bay project was approximately 42 million gal/year. The volume of effluent returned by the Village West Marina project is unknown. Staff estimated that the annual weight of mercury returned by the Discovery Bay dredge effluent was 0.008 kg, assuming that all water was returned.
(m) Annual averages do not include KFM, a one-time project.
(n) The uncertainty associated with the amount of mercury removed by dredging in the Sacramento Deep Water Ship Channel is particularly substantial (±446 kg), as a consequence of its calculation being based on only two sample results (0.68 and 0.061 mg/kg mercury) that have a tenfold range.

6.3.4 Other Potential Loss Pathways

Accumulation by biota and photodegradation throughout the Delta has not yet been evaluated. The amount of methylmercury accumulating in aquatic biota is not known. However, studies could be undertaken to ascertain the rate of transfer from the abiotic to the biotic component of the food web. Preliminary study results for the Sacramento River near Rio Vista indicate relative surface water photodegradation rates of about 30% of the dissolved methylmercury per day at the top half meter of water (Byington *et al.*, 2005). Byington and others' preliminary results are similar to photodegradation rates observed in Florida and Canada. Methylmercury photodegradation rates in a boreal forest lake in northwestern Ontario, Canada, ranged between -3 and 27% per day, with the highest rates at the lake surface (Sellers & Kelly, 2001). In the Everglades, Krabbenhoft and others (1999) observed methylmercury degradation rates ranging from 2 to 15% per day. Krabbenhoft and others (1999 & 2002) also found that the majority of photodegradation occurred in the top half meter of water; however, they also found that the rate of degradation was largely dependent on the concentration of dissolved organic carbon. The large surface to depth ratio of the Delta, coupled with its relatively long residence time, may result in significant loss of methylmercury by photodegradation. Byington and others' extrapolation of their preliminary study results suggests a loss of about 4 g/day over the entire Delta. Photodemethylation experiments are continuing as part of an ongoing CALFED-funded project (Proposal ERP-02-C06-B).

6.4 Delta Methylmercury Mass Budget & East-West Concentration Gradient

Figure 6.11 provides an idealized illustration of the Delta's average daily methylmercury imports and exports based on the annual loads presented in Tables 6.2 and 6.15. *In situ* sediment production and tributary water bodies account for about 30 and 60%, respectively, of methylmercury inputs to the Delta. Agricultural return flow and NPDES-permitted wastewater treatment plants are responsible for about 7% of the load while urban runoff contributes about half a percent.

The difference between the sum of known inputs and exports is a measure of the uncertainty of the loading estimates and of the importance of other unknown processes at work in the Delta. As noted in Section 6.2, the sum of WY2000-2003 water imports and exports balances within approximately 2%, indicating that all the major water inputs and exports have been identified. In contrast, the methylmercury budget does not balance. Average annual methylmercury inputs and exports were approximately 13.5 g/day (4.9 kg/yr) and 6.7 g/day (2.5 kg/yr), respectively (Tables 6.2 and 6.15 and Figure 6.11). Exports are only about 50% of inputs, suggesting that the Delta acts as a net sink for methylmercury.

A special study was conducted in the summer of 2001 to ascertain the location where much of the decrease in methylmercury occurred (Foe, 2003). Three transects were run down the Sacramento River and out toward San Francisco Bay, the water path from the main tributary source (Sacramento River) to the main export of methylmercury (Suisun Bay). The largest decrease in concentration consistently occurred in the vicinity or immediately downstream of Rio Vista (Figure 6.12). The drop in concentration was between 30 and 60%. The processes contributing to the loss are not known but are the subject of ongoing CALFED research (ERP-02-C06-B, Tasks 5A and 5B). For example, as described in the previous section, preliminary photodegradation study results for the Sacramento River near Rio Vista indicate relative surface water photodegradation rates of about 30% of the dissolved methylmercury per day at the top half meter of water (Byington *et al.*, 2005). Byington and others' extrapolation of their preliminary study results over all Delta waters suggests a loss of about 4 g/day, nearly 60% of the 6.7 g/day unknown loss rate illustrated in Figure 4.11. Additional research is ongoing or proposed in Chapter 4 of the draft BPA report (Implementation) that includes monitoring to better characterize source concentrations and loads. Improvements made to the load estimates could affect the methylmercury load allocations calculated in Chapter 8.

Key points for the methylmercury source analysis are listed after Figures 6.11 and 6.12.

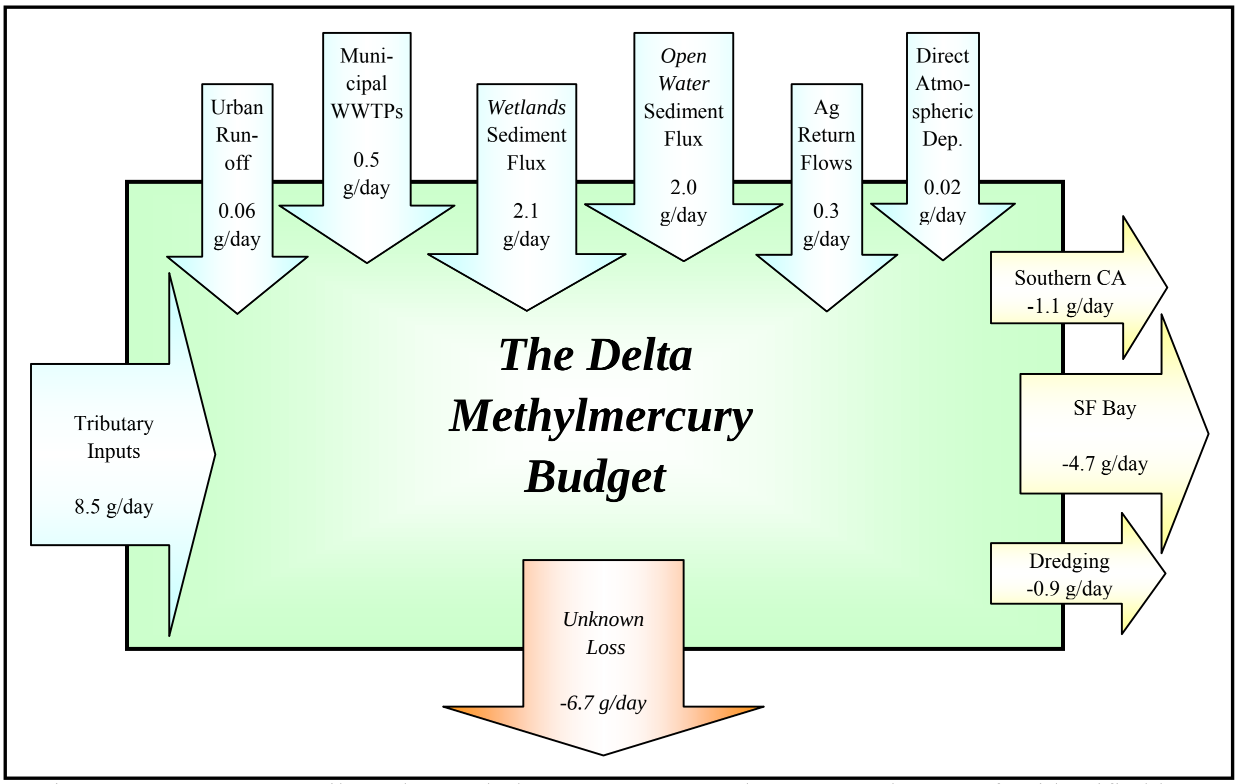

Figure 6.11: Average Daily Delta Methylmercury Inputs and Exports. The rate of unidentified loss processes was determined by subtracting the sum of the inputs from the sum of the exports.

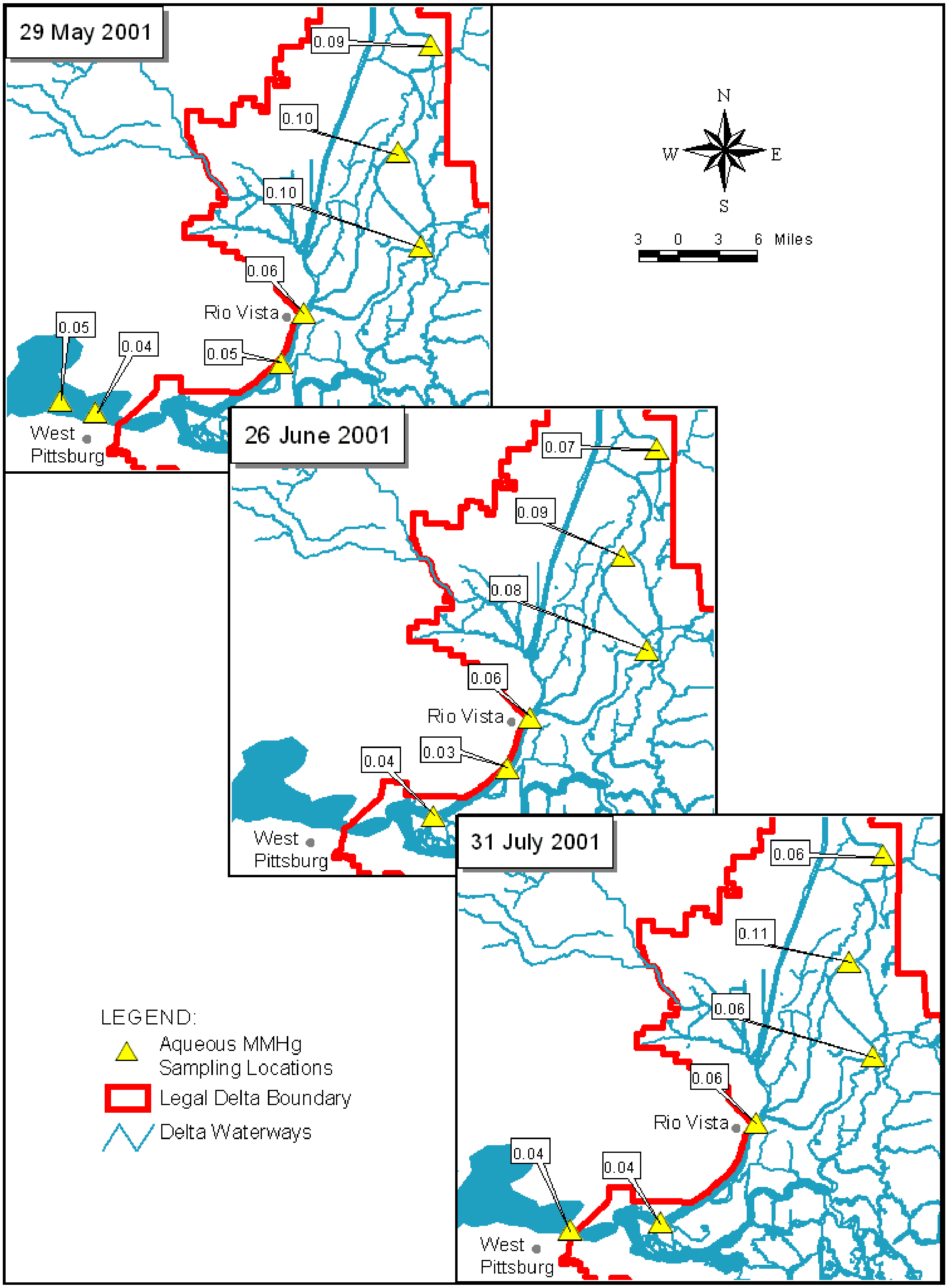

Figure 6.12: Water Sampling Transects down the Sacramento River to Ascertain Location of Methylmercury Concentration Decrease. Westernmost sampling stations changed with each transect depending on the locations of 1 o/oo through 5 o/oo bottom salinities, which move as a function of tidal cycle and freshwater inflow. Data source: Foe, 2003.

Key Points

- Sources of methylmercury in Delta waters include tributary inflows from upstream watersheds and within-Delta sources such as sediment flux, municipal and industrial wastewater, agricultural drainage, and urban runoff. Approximately 63% of identified methylmercury loading to the Delta comes from tributary inputs while within-Delta sources account for approximately 37% of the load.
- Losses include water exports to southern California, outflow to San Francisco Bay, removal of dredged sediments, photodegradation, uptake by biota and unknown loss term(s). Outflow to San Francisco Bay accounted for more than 70% of identified methylmercury exports.
- The sum of WY2000-2003 water imports and exports balances within approximately 2%, indicating that all the major water inputs and exports have been identified. In contrast, the methylmercury budget does not balance. A comparison of the sum of identified inputs (4.9 kg/yr) and exports (2.5 kg/yr) indicates that there is an unknown loss term of approximately 50%. Preliminary study results suggest that photodegradation may explain about 60% of the loss.

7 SOURCE ASSESSMENT – TOTAL MERCURY & SUSPENDED SEDIMENT

Sources and losses of total mercury and suspended sediment are described in this chapter. The Delta mercury TMDL program addresses total mercury in addition to methylmercury because:

- Methylmercury production has been found to be a function of the total mercury content of the sediment (Chapter 3) and decreasing total mercury loads may be an option for controlling methylmercury;
- The mercury control program for the Delta must maintain compliance with the USEPA's CTR criterion of 50 ng/l for total recoverable mercury for freshwater sources of drinking water developed for human protection; and
- The mercury TMDL for San Francisco Bay assigns a total mercury load reduction to the Central Valley watershed to protect human and wildlife health in the San Francisco Bay (Johnson & Looker, 2004). The San Francisco Bay Basin Plan requires the attainment of the total mercury load allocation to be demonstrated by a net 110 kg/yr decrease in five-year average annual total mercury loads entering the Delta or fluxing past Mallard Island. Meeting the San Francisco Bay goal will require an understanding of total mercury and sediment discharge to the Delta.

Sections 7.1 and 7.2 describe the total mercury and suspended sediment concentrations (measured as total suspended solids, or TSS) for Delta sources and losses and identify major data gaps and uncertainties. The water volume calculations upon which the load calculations are based are described in Section 6.1 and Appendix E. Input and loss loads were evaluated for the WY2000-2003 period, a relatively dry period that encompasses the available methylmercury concentration data for the major Delta inputs and exports. In addition, the WY1984-2003 period was evaluated to illustrate the importance of wet years, particularly for loading from the Yolo Bypass. This 20-year period includes a mix of wet and dry years that is statistically similar to what has occurred in the Sacramento Basin over the last 100 years. An assessment of a typical distribution of wet and dry water years is critical to the understanding of mercury and sediment sources because, as illustrated in the daily total mercury load graphs in Appendix J, the load for several high flow days may be equivalent to the annual load of the system during a dry year.

All the mass load calculations were developed using Equation 6.1. Section 7.3 presents the total mercury and suspended sediment mass budgets based on the input and export loads described in Sections 7.1 and 7.2. Section 7.4 reviews the mercury-to-TSS ratio (TotHg:TSS) for each input and export to identify areas that may be the focus of future remediation efforts to reduce total mercury loading. As described in Chapter 8 of this report and Chapter 4 of the Proposed Basin plan Amendment draft staff report, the total mercury limits and implementation plans for total mercury reduction will focus on sources that have both relatively large mercury loadings and high TotHg:TSS ratios.

7.1 Total Mercury and Suspended Sediment Sources

The following were identified as sources of total mercury and suspended sediment to the Delta: tributary inflows from upstream watersheds, municipal wastewater, atmospheric deposition, and urban runoff. Table 7.1 lists the estimated loads associated with these sources for the WY2000-2003 and WY1984-2003

Table 7.1: Average Annual Total Mercury and TSS Source Loads and Confidence Intervals for WY2000-2003 and WY1984-2003. (a)

	WY2000-2003				WY1984-2003			
	TotHg		TSS		TotHg		TSS	
	(kg/yr)	% of All Inputs	(Mkg/yr)	% of All Inputs	(kg/yr)	% of All Inputs	(Mkg/yr)	% of All Inputs
Tributary Inputs (b)								
Sacramento River	149 ±#	67%	689 ±#	63%	183 ±#	46%	865 ±#	40%
Prospect Slough	36 ±#	16%	195 ±#	18%	161 ±#	41%	984 ±#	46%
San Joaquin River	19 ±#	8.5%	146 ±#	13.4%	30 ±#	7.6%	235 ±#	11.0%
Calaveras River	3.6 ±#	1.6%	14 ±#	1.3%	3.8 ±#	1.0%	15 ±#	0.7%
Mokelumne-Cosumnes River	3.1 ±#	1.4%	8.6 ±#	0.8%	4.2 ±#	1.1%	11 ±#	0.5%
Ulatis Creek	2.0 ±#	0.9%	15.2 ±#	1.4%	2.1 ±#	0.5%	16 ±#	0.7%
French Camp Slough	1.6 ±#	0.72%	2.3 ±#	0.21%	1.7 ±#	0.43%	2.4 ±#	0.11%
Morrison Creek	0.80 ±#	0.36%	3.4 ±#	0.31%	0.86 ±#	0.22%	4.7 ±#	0.22%
Marsh Creek	0.54 ±#	0.24%	1.1 ±#	0.11%	0.54 ±#	0.14%	1.1 ±#	0.05%
Bear/Mosher Creeks	0.28 ±#	0.13%	2.2 ±#	0.21%	0.29 ±#	0.07%	2.3 ±#	0.11%
Sum of Tributary Sources:	**215** ±#	**96.8%**	**1,077** ±#	**99.3%**	**387 ±#**	**98.1%**	**2,137 ±#**	**99.6%**
Within-Delta Sources (c)								
Wastewater (Municipal & Industrial)	2.4 ±#	1.1%			2.4 ±#	0.61%		
Urban	2.5 ±#	1.1%	8.0 ±#	0.74%	2.6 ±#	0.66%	8.3 ±#	0.39%
Atmospheric (Indirect) (d)	1.4 ±#	0.63%			1.5 ±#	0.38%		
Atmospheric (Direct) (d)	0.9 ±#	0.38%			0.89 ±#	0.23%		
Sum of Within-Delta Sources:	**7.4 ±#**	**3.2%**	**8.0 ±#**	**0.7%**	**7.7 ±#**	**1.9%**	**8.3 ±#**	**0.4%**
TOTAL INPUTS:	**223 ±#**	**100%**	**1,085 ±#**	**100%**	**395 ±#**	**100%**	**2,145** ±#	**100%**

(a) The 95% confidence limits will be calculated using a method developed in consultation with UC Davis that will be described in Appendix J once completed.
(b) Total mercury and TSS concentration data are not available for other small drainages to the Delta, including the following areas shown on Figure 6.1: Dixon, Upper Lindsay/Cache Slough, Manteca-Escalon, Bethany Reservoir, Antioch, and Montezuma Hills areas.
(c) Total mercury and sediment loading data for any erosion of Delta soils are not available.
(d) The uncertainty of the atmospheric deposition load estimates was not evaluated.

periods. Tributary sources account for almost all the total mercury and TSS fluxing though the Delta, with more than 80% of the loading coming from the Sacramento Basin. The following sections describe the available concentration data and identify some of the data gaps and uncertainties associated with the load estimates.

7.1.1 Tributary Inputs

During WY2000-2003, tributaries to the Delta contributed approximately 97% of the total mercury and 99% of the suspended sediment (Table 7.1). The Sacramento Basin alone (Sacramento River at Freeport + Yolo Bypass) contributed more than 80% of all mercury and TSS loading to the Delta. The load estimates illustrated in Table 7.1 are based on the water volumes described in Section 6.1 and Appendix E, and concentration data collected by several agencies.

Central Valley Water Board staff began evaluating mercury loading from the Sacramento River watershed and Yolo Bypass to the Delta in 1994 (Foe & Croyle, 1998). From March 2000 to September 2001, staff conducted monthly sampling at the Delta's four major tributary input sites (Foe, 2003): Sacramento River; San Joaquin River; Mokelumne River (downstream of the Mokelumne/Cosumnes Rivers confluence); and Prospect Slough at Toe Drain in the Yolo Bypass. In addition, other programs conducted periodic aqueous sampling between 1993 and 2003 on the Sacramento River (SRWP, 2004; CMP, 2004; Stephenson *et al.*, 2002). Central Valley Water Board staff resumed sampling in April 2003. Figure 6.2 shows the tributary monitoring locations. Table 7.2 and Figures J.1 through J.3 in Appendix J summarize the available total mercury and TSS concentration data for the Delta's tributary inputs.

Sections 7.1.1.1 through 7.1.1.3 describe the methods used to estimate the loads for the Delta's tributary watersheds and identify uncertainties. Because the Sacramento Basin is the primary source of mercury to the Delta, Section 7.1.1.3 provides an analysis of loading from the tributaries that contribute to the Sacramento Basin exports to the Delta. In addition, Section 7.1.1.4 evaluates compliance of Delta and Sacramento Basin tributary waters with the CTR. The Sacramento Basin tributary evaluation is needed to develop the total mercury limits and implementation strategies described in Chapter 8 in this TMDL report and Chapter 4 in the Proposed Basin Plan Amendment draft staff report. Specific sources of total mercury within the Sacramento Basin tributary watersheds upstream of the legal Delta boundary – for example, historic mining operations and erosion of naturally mercury-enriched soils – will be evaluated in the implementation phase of this TMDL (see Chapter 4 in the Proposed Basin Plan Amendment draft staff report) and in the TMDL programs for those watersheds.

7.1.1.1 Sacramento Basin Inputs to the Delta

Sacramento Basin total mercury and TSS discharges to the Delta were evaluated at the Sacramento River at Freeport and the Yolo Bypass at Prospect Slough. Total mercury and TSS concentrations for the Sacramento River at Freeport were regressed against Freeport flow data to determine if correlations existed. Both regressions were statistically significant at $P < 0.01$. The statistically significant correlations indicate that it is possible to predict Sacramento River mercury and TSS concentrations from flow. Therefore, the mercury/flow and TSS/flow equations were used to predict average annual loads

Table 7.2: Total Mercury and TSS Concentrations for Tributary Inputs

Site (a)	**# of Samples**	**Sampling Begin Date**	**Sampling End Date**	**Min. Conc.** (ng/l)	**Ave. Conc.** (ng/l)	**Median Conc.** (ng/l)	**Max. Conc.** (ng/l)
TOTAL MERCURY CONCENTRATIONS							
Bear/Mosher Creeks (b)	4	03/15/03	02/26/04	3.55	8.15	8.84	11.36
Calaveras River @ RR u/s West Lane (b)	4	03/15/03	02/26/04	13.23	20.53	21.34	26.22
French Camp Slough near Airport Way	7 [4]	01/28/02	02/26/04	1.73 [3.32]	12.9 [20.5]	3.40 [11.63]	55.42 [55.42]
Marsh Creek @ Hwy 4	19 [3]	11/05/01	02/02/04	0.93	7.31	4.36	30.18
Mokelumne River @ I-5	21	03/28/00	09/30/03	0.26	5.34	5.19	12.28
Morrison Creek (c)	47 [15]	04/09/97	01/28/02	1.62 [3.9]	7.96 [10.46]	7.23 [9.12]	19.75 [19.75]
Prospect Slough (Yolo Bypass) (d)	28 (26)	01/10/95	09/30/03	7.18	73.10 (30.67)	26.70 (25.73)	695.6 (92.2)
Sacramento River @ Freeport	155	02/15/94	11/06/02	1.20	8.28	6.31	36.19
San Joaquin River @ Vernalis	35	10/29/93	02/26/04	3.12	8.18	7.22	23.54
Ulatis Creek near Main Prairie Rd	6 [4]	01/28/02	02/26/04	1.34 [24.21]	36.06 [53.24]	28.68 [52.51]	83.74 [83.74]
TSS CONCENTRATIONS							
Bear/Mosher Creeks (b)	4	03/15/03	02/26/04	15.8	65.8	24.1	199.1
Calaveras River @ RR u/s West Lane (b)	4	03/15/03	02/26/04	32.4	82.7	55.4	187.5
French Camp Slough near Airport Way	5 (4)	01/28/02	02/26/04	12.0 [16.7]	26.0 [29.5]	26.4 [27.5]	46.5 [46.5]
Marsh Creek @ Hwy 4	7 (2)	04/28/02	02/02/04	17.9 [36.9]	69.1 [155.0]	36.9 [155.0]	273.2 [273.2]
Mokelumne River @ I-5	23	3/28/00	9/30/03	5.8	14.5	12.0	31.0
Morrison Creek (c)	44 (15)	04/09/97	01/28/02	6.0 [7.0]	39.9 [57.0]	27.0 [40.5]	140 [140]
Prospect Slough (Yolo Bypass) (d)	46 (24)	1/10/95	9/30/03	36.6	301.4 [170.0]	143.2 [139.9]	2300.7 [512.7]
Sacramento River @ Freeport	186	12/15/92	1/20/04	2.0	38.2	26.0	368.0
San Joaquin River @ Vernalis	34	3/28/00	2/26/04	20.0	64.4	58.6	175.0
Ulatis Creek near Main Prairie Rd	6 (4)	01/28/02	02/26/04	2.5 [140.2]	276.5 [411.6]	217.8 [338.4]	829.6 [829.6]

(a) Flow gage data were not available for most of the small tributary outflows to the Delta. Therefore, wet weather concentration data (noted in brackets), and estimated wet weather runoff (Section E.2.3 in Appendix E), were used to develop load estimates.

(b) Only wet weather events were sampled on the Calaveras River and Bear and Mosher Creeks in Stockton. The one wet weather Mosher Creek sample result was combined with the Bear Creek data to estimate loads for both creeks (Appendix J).

(c) Concentration data collected at multiple sites on lower Morrison Creek were compiled to develop load estimates creeks (Appendix J).

(d) Sampling took place at Prospect Slough (export location of the Yolo Bypass) both when there were net outflows from tributaries to the Yolo Bypass and when there was no net outflow (i.e., the slough's water was dominated by tidal waters from the south). The regression analysis focuses only on the conditions when there was net outflow from the Yolo Bypass. The above values do not include data collected when there was no net outflow. The values in parentheses are from calculations without the two very high values shown in Figure J.1. The regression is between total mercury concentrations observed at Prospect Slough (not including the two very high values shown in Figure J.1) and total export flows for the previous day estimated for Lisbon Weir, approximately 15 miles north of the Prospect Slough sampling station. The previous day's flow values were used to address the approximate residence time of the water as it travels through the Yolo Bypass to the export location where samples were collected.

Table 7.3: Comparison of Loading Estimates for Sacramento Basin Discharges to the Delta

Study	Sampling Location	Period	Average Sacramento Valley Water Year Hydrologic Index (a)	Average Annual TotHg Load [Upper & Lower Limits] (kg) (d)	Average Annual TSS Load [Upper & Lower Limits] (Mkg) (d)
Sacramento River					
Delta Mercury TMDL	Freeport	WY2000-2003	7.3	149 [#, #]	689 [#, #]
		WY1984-2003	7.8	183 [#, #]	865 [#, #]
Foe and Croyle (1998)	Greene's Landing	May 1994- April 1995	12.9	426	1,400
Foe (2002)	Greene's Landing	WY2001 (b)	5.8	91	526
LWA (2002)	Freeport	WY1980-1999	8.5	188.9 [187.0,190.7]	na
Wright & Schoellhamer (2005)	Freeport	WY1999-2002	7.7	na	1,100 [930, 1270]
Yolo Bypass					
Delta Mercury TMDL	Prospect Slough	WY2000-2003	7.3	36 [#, #]	195 [#, #]
		WY1984-2003	7.8	161 [#, #]	984 [#, #]
Foe and Croyle (1998)	Prospect Slough	May 1994- April 1995	12.9	375	2,500
Foe (2002)	Prospect Slough	WY2001 (d)	5.8	3.8	42
LWA (2002)	Woodland	WY1980-1999	8.5	117.5 [125.5, 134.1]	na
Wright & Schoellhamer (2005)	Woodland	WY1999-2002	7.7	na	310 [180, 440]
Sacramento Basin Total (Sacramento River + Yolo Bypass)					
Delta Mercury TMDL		WY2000-2003	7.3	185 [#, #]	884 [#, #]
		WY1984-2003	7.8	344 [#, #]	1,849 [#, #]
Foe and Croyle (1998)		May 1994- April 1995	12.9	801	3,900
Foe (2002)		WY2001 (d)	5.8	94.8	568
LWA (2002)		WY1980-1999	8.5	306	na
Wright & Schoellhamer (2005)		WY1999-2002	7.7	na	1,410 [1110, 1710]
Domagalski (2001) (c) 3 winter seasons, 20 December to 20 March		WY1997	10.8	487	na
		WY1998	13.3	506	na
		WY1999	9.8	169	na

(a) Source: DWR, http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST. DWR calculated a hydrologic index for the Sacramento Valley (Section E.2.1 in Appendix E). "Normal" hydrologic conditions for the Sacramento Valley are represented by an index value of 7.8, "wet" is ≥9.2, "dry" is between 5.4 and 6.5, and "critical dry" is ≤5.4. Figure E.1 in Appendix E illustrates the indices for each water year for the period of record.

(b) Foe's 2002 CALFED study estimated monthly total mercury and TSS loads for March 2000 through September 2001, but did not include load estimates for November 2000. November total mercury and TSS loads for WY2001 were estimated by averaging the loads for October and December 2000.

(c) Domagalski (2001) reported winter mercury loads from the Sacramento Basin for WY1997 through 1999 based on data collected at Sacramento River at Freeport and Yolo Bypass at Interstate 80 (upstream of Putah Creek inputs), but did not report individual loads for the Sacramento River and Yolo Bypass.

(d) The 95% confidence limits will be calculated for the TMDL loads using the method developed in consultation with UC Davis and will be described in Appendix J once completed.

from the Sacramento River watershed entering the Delta,[36,37] resulting in estimated average annual loads of 149 kg mercury and 689 Mkg TSS for WY2000-2003, and 183 kg mercury and 865 Mkg TSS for WY1984-2003 (Tables 7.1 and 7.3). Regression uncertainty will be evaluated by calculating the 95% confidence intervals for the mean response (in progress; Helsel and Hirsch, 2002),[38] which will be presented as the lower and upper load limits in Tables 7.1 and 7.3.

Prospect Slough is the main channel draining the Yolo Bypass. Total mercury and TSS samples were collected in Prospect Slough during outgoing tides. Total mercury and TSS concentrations observed on dates when there appeared to be net outflow from Lisbon Weir were regressed against estimated daily Yolo Bypass outflows at Lisbon Weir lagged by one day[39] to determine if statistically significant correlations might exist (Section E.2.2 in Appendix E & Appendix J, Figure J.1). Extremely high total mercury and TSS concentrations were measured on 10 and 11 January 1995 (Figure J.1). These values were not included in the regressions because, as described in Section E.2.2, the hydrologic conditions that probably caused these events appear to have occurred only once during the WY1984-2003 study period. The TotHg/flow and TSS/flow regressions were significant at $P< 0.01$ (Figure J.1), indicating that the concentrations of both constituents could be predicted from flow. The regressions were used to estimate annual average loads of 36 kg mercury and 195 Mkg TSS for WY2000-2003 (Table 7.1), and 161 kg mercury and 984 Mkg TSS for WY1984-2003 (Table 7.3). The estimated mercury and TSS loads for the WY1984-2003 period illustrate the importance of wet years on loading from the Yolo Bypass.

Several studies have evaluated total mercury and suspended sediment loading from the Sacramento Basin for a variety of wet and dry years (Table 7.3). These studies are summarized below. The results of these studies will be evaluated in the context of the confidence limits of the TMDL total mercury and suspended sediment load calculations once the 95% confidence limits have been completed.

Foe and Croyle (1998) reported loading estimates of approximately 426 kg total mercury and 1,400 Mkg TSS for the Sacramento River at Greene's Landing, and 375 kg mercury and 2,500 Mkg TSS for the Yolo Bypass at Prospect Slough for May 1994 through April 1995, a very wet period. In contrast, Foe (2002) reported loading estimates of about 91 kg mercury and 526 Mkg TSS for Greene's Landing, and 3.8 kg

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[36] For all tributaries with statistically significant TotHg/flow or TSS/flow relationships, the predicted concentrations were multiplied by daily flow volumes to estimate daily loads. The estimated daily loads were summed and then divided by the number of years in the study period to estimate the average annual loads for WY2000-2003. If a flow record had dates with missing values, the data were normalized to estimate annual loads. For example, a 20-year record would be normalized by dividing 7305 (the number of days in the 20-year period) by the number of days with a recorded value in the flow record and then multiplying the resulting quotient by the calculated sum of loads; the result was then divided by 20 to obtain the average annual load.

[37] The Delta area that drains to the 13-mile reach of the Sacramento River between Freeport (near river mile 46) and the I Street Bridge (the northernmost legal Delta boundary, near river mile 59) is predominantly urban and is encompassed by the urban load estimate described in Section 5.2.5. No attempt was made to subtract this area from the Sacramento River watershed load estimate. Therefore, the Sacramento River load noted in Table 7.1 incorporates a small portion of the within-Delta urban runoff loading.

[38] Appendix J will describe the method used to calculate the intervals.

[39] The estimated daily flows from Lisbon Weir on Toe Drain were lagged one day to address the approximate residence time of water along the ~15 miles between Lisbon Weir and Prospect Slough. There is generally no net outflow from the Yolo Bypass's Toe Drain downstream of Lisbon Weir between April and November. (See Appendix E for a description of Yolo Bypass hydrology.) Therefore, although sampling of Prospect Slough took place during outgoing tides with the intent of sampling outflows from the Yolo Bypass, during the summer months this sampling most likely represents waters tidally-pumped northward from Cache Slough, rather than outflows from the Yolo Bypass north of Lisbon Weir.

mercury and 42 Mkg TSS for the Yolo Bypass, during WY2001,[40] a dry period with limited outflows from the Yolo Bypass (Figure E-2).

LWA (2002) reported average annual mercury loading estimates of 189 kg/yr for the Sacramento River at Freeport and 126 kg/yr for the Yolo Bypass (Table 7.3). This study used flow data for 1980-1999, a period that was wetter than the TMDL periods, and concentration data collected during 1993-2000, an exceptionally wet period. LWA (2002) estimated an average annual total mercury load from the Yolo Bypass of using 1980-1999 flow data from the USGS gage, Yolo Bypass at Woodland, and concentration data collected during 1993-2000.

Wright and Schoellhamer (2005) estimated an average annual suspended sediment load of approximately 1,100 Mkg/yr for the Sacramento River at Freeport for WY1999-2002 (a wetter period, Table 7.3). The authors also estimated an average annual water flux of 1.7 x 10^9 m^3 (1.4 M acre-feet) and a suspended sediment flux of approximately 310 Mkg/yr for the Yolo Bypass for WY1999-2002. Their suspended sediment load estimate is based on flow estimates from the Dayflow model and daily suspended-sediment flux records for the Yolo Bypass developed using a rating curve based on data collected at the Woodland flow gage.[41]

Domagalski (2001) estimated the amount of total mercury transported out of the Sacramento Basin during three winters: 487 kg for WY1997, 506 kg for WY1998, and 169 kg for WY1999. All three of the periods correspond to relatively wet periods in the Sacramento Valley (Table 7.3). WY1998 was exceptionally wet. Domagalski noted that precipitation in the Sacramento Valley during this period was lower than average while the precipitation in the Sierra Nevada was higher than average, such that much less water was transported out of the basin through the Yolo Bypass, which may account for its relatively low loading compared to Foe & Croyle's estimate for a similar wet year, WY1995.

7.1.1.2 Other Tributary Inputs to the Delta

The TotHg/flow and TSS/flow regressions for the Mokelumne and San Joaquin Rivers were not significant ($P > 0.05$). Therefore, the average mercury and TSS concentrations (Table 7.2) for these locations were multiplied by average annual flow volumes for WY2000-2003 and WY1984-2003 (Table 6.1) to estimate average annual loads. The Mokelumne River has estimated average annual loads of 3.1 kg mercury and 8.6 Mkg TSS for WY2000-2003, and 4.2 kg mercury and 11 Mkg TSS for WY1984-2003 (Table 7.1). The San Joaquin River has estimated average annual loads of 19 kg mercury and 146 Mkg TSS for WY2000-2003, and 30 kg mercury and 235 Mkg TSS for WY1984-2003.

Several other studies have evaluated total mercury and suspended sediment loading from the Delta's tributaries for a variety of wet and dry years (Table 7.4). LWA (2002) estimated Mokelumne and San Joaquin Rivers average annual total mercury loadings for 1980-1999 at 3 kg/yr and 26 kg/year, respectively. Foe (2002) estimated Mokelumne River total mercury and TSS loadings of approximately 1.5 kg and 5.2 Mkg, and San Joaquin River total mercury and TSS loadings of approximately 16 kg and

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[40] Foe's 2002 CALFED study estimated monthly total mercury and TSS loads for March 2000 through September 2001, but did not include load estimates for November 2000. November total mercury and TSS loads for WY2001 were estimated by averaging the loads for October and December 2000.

[41] Wright and Schoellhamer's Yolo Bypass sediment data includes 45 sediment flux measurements between 1957 and 1961 and three measurements in 1980.

110 Mkg, for WY2001, a drier water year. Wright and Schoellhamer (2005) estimated an average annual suspended sediment load of approximately 210 Mkg/yr for the San Joaquin River for WY1999-2002 (a wetter period). The results of these studies will be evaluated in the context of the confidence limits of the TMDL total mercury and suspended sediment load calculations for the Mokelumne and San Joaquin Rivers once their 95% confidence limits have been completed. Nonetheless, it is obvious that both mercury and sediment discharges from the San Joaquin River and Mokelumne River are much less than discharges from the Sacramento Basin.

Table 7.4: Comparison of Loading Estimates for Other Major Delta Tributaries

Study	Period	Average San Joaquin Valley Water Year Hydrologic Index (a)	Average Annual TotHg Load [Upper & Lower Limits] (kg) (c)	Average Annual TSS Load [Upper & Lower Limits] (Mkg) (c)
San Joaquin River @ Vernalis				
Delta Mercury TMDL	WY2000-2003	2.7	19 [#, #]	146 [#, #]
	WY1984-2003	3.1	30 [#, #]	235 [#, #]
Foe (2002)	WY2001 (b)	2.2	16	110
LWA (2002)	WY1980-1999	3.5	26	na
Wright & Schoellhamer (2005)	WY1999-2002	2.9	na	210 [231, 189]
Mokelumne River downstream of Cosumnes River Confluence				
Delta Mercury TMDL	WY2000-2003	2.7	3.1 [#, #]	8.6 [#, #]
	WY1984-2003	3.1	4.2 [#, #]	11 [#, #]
Foe (2002)	WY2001 (b)	2.2	1.5	5.2
LWA (2002)	WY1980-1999	3.5	3	na
Eastside Tributaries (Cosumnes, Mokelumne & Calaveras Rivers & French Camp Slough)				
Delta Mercury TMDL	WY2000-2003	2.7	8.3 [#, #]	25 [#, #]
	WY1984-2003	3.1	9.7 [#, #]	28 [#, #]
Wright & Schoellhamer (2005)	WY1999-2002	2.9	na	36 [28, 44]

(a) Source: DWR, http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST. DWR calculated a hydrologic index for the San Joaquin Valley (Section E.1 in Appendix E). "Normal" hydrologic conditions for the San Joaquin Valley are represented by an index value of 3.1, "wet" is ≥3.8, "dry" is 2.1 to 2.5, and "critical dry" is ≤2.1.

(b) Foe's 2002 CALFED study estimated monthly total mercury and TSS loads for March 2000 through September 2001, but did not include load estimates for November 2000. November total mercury and TSS loads for WY2001 were estimated by averaging the loads for October and December 2000.

(c) The 95% confidence limits will be calculated for the TMDL loads using the method developed in consultation with UC Davis and will be described in Appendix J once completed.

The regression between total mercury concentration and flow for Marsh Creek was statistically significant, but the TSS/flow regression was not. The resulting regression equation for total mercury was used to estimate daily total mercury concentrations. The predicted total mercury concentrations were multiplied by daily flow volume at the Brentwood gage to estimate daily loads, which were summed and then divided by the number of years in the flow gage record to estimate the average annual loads. The Marsh Creek total mercury and TSS loads shown in Table 7.1 represent the average annual loads for WY2001-2003 because the Brentwood flow gage was not operational during WY2000. Because the TSS/flow regression was not significant at $P < 0.05$, the average wet weather TSS concentration was multiplied by average annual flow volume to estimate WY2001-2003 average annual loads.

There were no flow gages available for watershed outflow sampling locations on several small eastside and westside tributaries: Morrison Creek, Bear Creek, Mosher Creek, French Camp Slough, and Ulatis Creek. The average wet season total mercury and TSS concentrations (Table 7.4) were multiplied by estimated average annual rainfall runoff volumes (Table 6.1 and Section E.2.2 in Appendix E) to estimate average annual loads.

Wright and Schoellhamer (2005) estimated an average annual suspended sediment load of approximately 36 Mkg/yr for WY1999-2002 for the eastside tributaries, which include the Cosumnes and Mokelumne Rivers (the primary sources) as well as the Calaveras River and French Camp Slough. Their suspended sediment estimate is based on flow estimates from the Dayflow model, which provided an estimated annual water flux of about 0.81 M acre-feet, and daily suspended-sediment flux records for the Cosumnes and Mokelumne Rivers developed using rating curves. The Cosumnes River rating curve is based on data collected from the USGS gage near Michigan Bar (about 36 river miles upstream of the statutory Delta boundary), which include 80 flux measurements between 1965 and 1974 and 13 measurements during WY2002. The Mokelumne River rating curve is based on data from the USGS gage at Woodbridge (about 15 river miles upstream of the statutory Delta boundary), which include 125 flux measurements between 1974 and 1994. The sum of the WY2000-2003 average annual water volumes provided in Table 6.1 for the Mokelumne-Cosumnes, Calaveras, and French Camp Slough outflows to the Delta is 0.64 M acre-feet. The sum of WY2000-2003 average annual TSS loads provided in Table 7.1 for these watersheds is 25 Mkg, a load estimate that is similar to Wright and Schoellhamer's load estimate for eastside tributaries.

7.1.1.3 Sacramento Basin Tributary Watersheds Loads

Because Sacramento Basin outflows account for about 80% of all mercury and TSS loading to the Delta, evaluation of the loading from its tributary watersheds is needed to develop total mercury limits and implementation strategies for mercury reductions in Delta biota and outflows to the San Francisco Bay. During low flow conditions, water in the Sacramento River at Freeport primarily originates from Shasta and Oroville Dams in the upper Sacramento and Feather River basins, respectively (Figure 7.1). In contrast, during large storms the Sacramento River at Freeport may be dominated by flows from the American and Feather Rivers. Storm overflow from the upper Sacramento River, Feather River and Colusa Basin are routed down the Yolo Bypass. The Yolo Bypass also receives flows from Putah Creek and Cache Creek *via* the Cache Creek Settling Basin. The Settling Basin is located at the base of the Cache Creek watershed and currently captures about half of the sediment and mercury transported by Cache Creek (Foe and Croyle, 1998; CDM, 2004; Cooke *et al.*, 2004); untrapped sediment is flushed into the Yolo Bypass.

Four-year (WY2000-2003) and 20-year (WY1984-2003) average annual loading values were calculated for the tributary watersheds that contribute to loads discharged from the Sacramento Basin to the Delta. Table 7.5 summarizes the total mercury and TSS concentration data available for the Sacramento Basin tributaries. Table 7.6 presents the watershed acreages, water volumes and estimated total mercury and

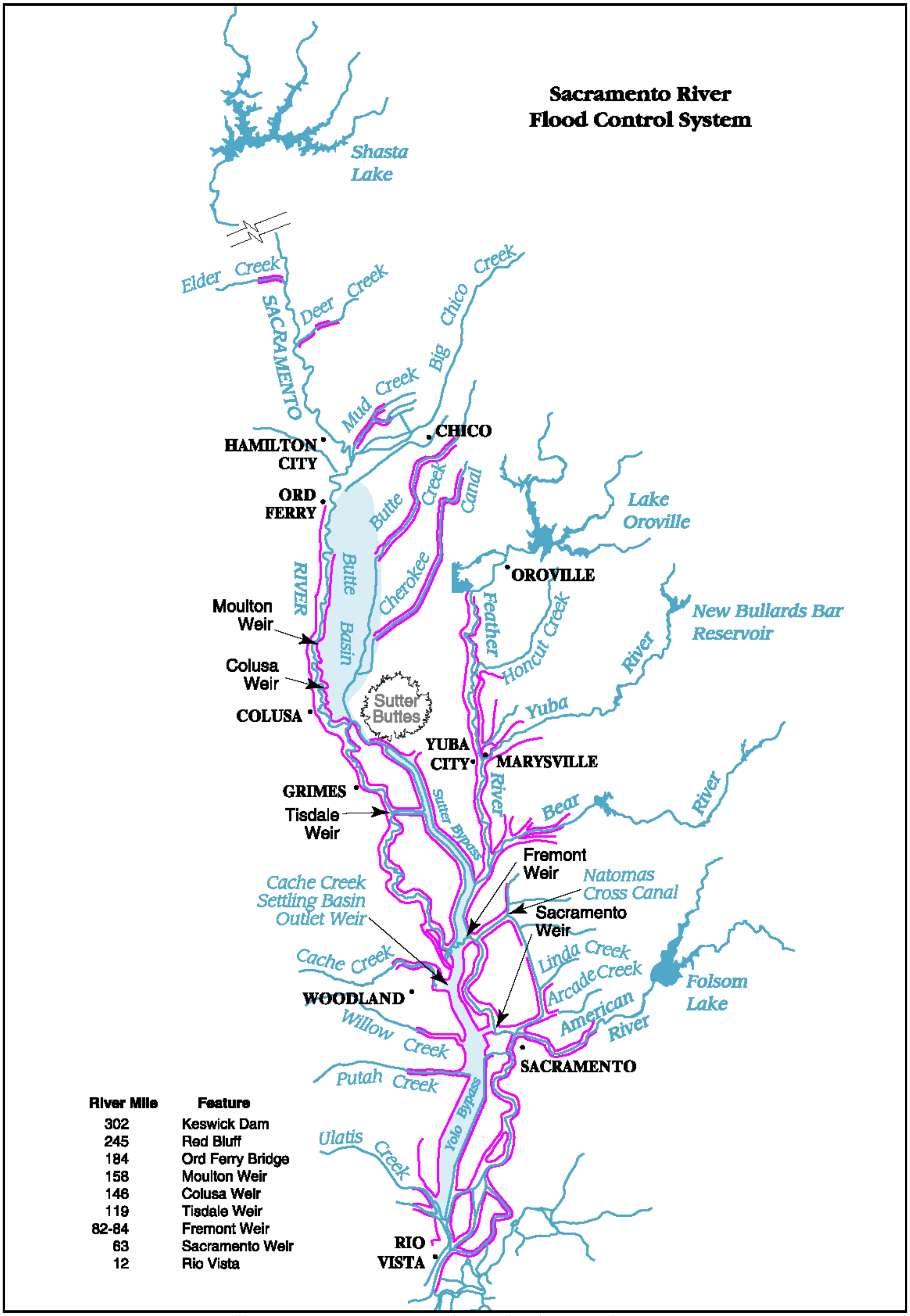

Figure 7.1: Sacramento River Flood Control System.
Pink lines represent levees. (Tetra Tech, 2005; DWR, 2003a)

Table 7.5: Total Mercury & TSS Concentrations for Sacramento Basin Tributaries.

Site	# of Samples	Sampling Begin Date	Sampling End Date	Min. Conc. (ng/l)	Average (ng/l)	Median Conc. (ng/l)	Max. Conc. (ng/l)
Total Mercury Concentrations							
American River @ Discovery Park	155	2/01/94	2/19/04	0.46	2.97	2.14	18.51
Cache Creek Settling Basin	26	12/23/96	2/17/04	4.07	185.73	63.04	984.60
Colusa Basin Drain	63	1/31/95	2/18/04	1.59	11.58	6.90	75.10
Feather River near Nicolaus	77	1/31/95	2/18/04	1.49	6.76	4.31	46.19
Natomas East Main Drain (a)	56 (12)	3/5/96	12/12/02	1.06 (9.52)	10.87 (27.78)	6.88 (20.84)	82.99 (82.99)
Putah Creek @ Mace Blvd.	36	1/31/95	3/09/04	1.25	33.10	9.29	485.00
Sacramento River above Colusa	68	3/10/95	2/17/04	0.60	12.18	4.08	105.16
Sacramento Slough near Karnak (b)	56	2/12/96	9/15/03	0.69	8.81	7.67	30.8
TSS Concentrations							
American River @ Discovery Park	191	12/15/92	2/19/04	0.5	6.23	3.0	116.0
Cache Creek d/s Settling Basin	24	12/23/96	2/17/04	41.0	452.7	187.5	1,900
Colusa Basin Drain	59	2/07/96	2/18/04	21.0	128.0	101.0	487.7
Feather River near Nicolaus	72	2/23/96	2/18/04	2.0	23.5	14.5	123.0
Natomas East Main Drain (a)	30 (8)	3/5/96	3/8/02	5.0 (16.6)	31.3 (43.0)	66.0 (34.5)	122.0 (96.0)
Putah Creek @ Mace Blvd.	27	3/28/00	2/29/04	1.6	53.4	30.0	417.8
Sacramento River above Colusa	51	3/10/95	2/17/04	10.0	101.6	36.0	662.2
Sacramento Slough near Karnak (b)	54	2/12/96	9/15/03	14.8	62.6	53.0	182.0

(a) No concentration or flow data gage data were available for Natomas East Main Drain outflows. The SRWP, USGS and City of Roseville collected total mercury and TSS concentration data on Arcade Creek near Norwood and Del Paso Heights and Dry Creek. Wet weather concentration data for Arcade Creek and Dry Creek (noted in parentheses), and estimated wet weather runoff for the entire Natomas East Main Drain watershed (Table 6.1 in Chapter 6 and Section E.2.2 in Appendix E), were used to develop preliminary load estimates. Note, Natomas East Main Drain was recently renamed "Steelhead Creek".

(b) Sacramento Slough near Karnak is the low flow channel for Sutter Bypass.

Table 7.6a: Sacramento Basin Tributaries – Acreage & Water Volumes.

	Acreage	% All Acreage	WY2000-2003 Water Volume (M acre-feet/yr)	WY2000-2003 % All Water	WY1984-2003 Water Volume (M acre-feet/yr)	WY1984-2003 % All Water
Upstream Tributary Inputs						
American River	1,253,740	7.5%	1.88	11%	2.5	12%
Cache Creek	724,526	4.3%	0.22	1.3%	0.38	1.9%
Colusa Basin Drain	1,577,307	9.4%	0.571	3.4%	0.574	2.8%
Coon Creek/Cross Canal	287,914	1.7%	0.089	0.5%	0.094	0.5%
Feather River	3,793,179	23%	3.7	22%	5.5	27%
Natomas East Main Drain	231,598	1.4%	0.064	0.4%	0.067	0.3%
Putah Creek	652,762	3.9%	0.24	1.5%	0.32	1.6%
Sacramento River above Colusa	7,562,525	45%	8.2	49%	8.1	40%
Sutter Bypass (a)	682,071	4.1%	1.8	11%	2.8	14%
Sum of Upstream Inputs:	**16,765,622**	**100%**	**16.8**	**100%**	**20.3**	**100%**
Exports to Delta						
Yolo Bypass (Prospect Slough)	- - -		1.0	6%	2.7	14%
Sacramento River (Freeport)	- - -		15.1	94%	16	86%
Sum of Exports to Delta:	- - -		**16.1**	**100%**	**18.8**	**100%**
Tributary Inputs – Exports to Delta:			**0.6**		**1.5**	
Exports to Delta / Tributary Inputs			**96%**		**93%**	

Table 7.6b: Sacramento Basin Tributaries – Total Mercury Loads.

	WY2000-2003			WY1984-2003			% of TotHg Inputs (Average)	
	Lower Limit	Average	Upper Limit	Lower Limit	Average	Upper Limit	WY2000-2003	WY1984-2003
Upstream Tributary Inputs								
American River	5.5	**6.5**	7.4	12	**14**	17	2.6%	3.4%
Cache Creek Settling Basin	15	**30**	45	95	**125**	154	12%	29%
Colusa Basin Drain	8.8	**8.9**	9.1	11	**11**	11	3.6%	2.7%
Feather River	18	**30**	35	36	**77**	96	12%	18%
Natomas East Main Drain	1.2	**2.2**	3.2	1.3	**2.3**	3.4	0.9%	0.5%
Putah Creek	1.3	**10**	19	1.7	**13**	24.7	4.1%	3.1%
Sacramento River above Colusa	95	**139**	184	105	**151**	197	57%	36%
Sutter Bypass (a)	16	**19**	22	26	**30**	35	7.8%	7.1%
Sum of Upstream Inputs:	161	**246**	324	288	**424**	538	100%	100%
Exports to Delta								
Prospect Slough	27	**36**	45	104	**161**	218	20%	47%
Sacramento River @ Freeport	131	**149**	166	162	**183**	204	80%	53%
Sum of Exports to Delta:	157	**185**	212	266	**344**	422	100%	100%
Trib Inputs - Exports to Delta		**61**			**80**			
Exports to Delta / Trib Inputs		**75%**			**81%**			

Table 7.6c: Sacramento Basin Tributaries – TSS Loads (Mkg/yr).

	WY2000-2003			WY1984-2003			% of TSS Inputs (Best Estimate)	
	Lower	Best Estimate	Upper	Lower	Best Estimate	Upper	WY2000-2003	WY1984-2003
Upstream Tributary Inputs								
American River	11	**14**	17	44	**53**	62	0.75%	2.2%
Cache Creek Settling Basin	40	**72**	105	205	**269**	333	3.8%	11%
Colusa Basin Drain	82	**103**	124	96	**129**	162	5.4%	5.2%
Feather River	77	**103**	130	179	**256**	332	5.5%	10%
Natomas East Main Drain	2	**3**	5	2	**4**	5	0.18%	0.14%
Putah Creek		**8**	17	7	**21**	34	0.4%	0.8%
Sacramento River above Colusa	1,153	**1,446**	1,738	1,223	**1,522**	1,821	77%	62%
Sutter Bypass (a)	115	**136**	156	182	**215**	248	7.2%	8.7%
Sum of Upstream Inputs:	1,479	**1,885**	2,291	1,940	**2,468**	2,996	100%	100%
Exports to Delta								
Prospect Slough	125	**195**	265	536	**984**	1,431	22%	53%
Sacramento River @ Freeport	575	**689**	803	729	**865**	1,002	78%	47%
Sum of Exports to Delta:	700	**884**	1,068	1,265	**1,849**	2,433	100%	100%
Trib Inputs - Exports to Delta		**1,001**			**619**			
Exports to Delta / Trib Inputs		**46.9%**			**75%**			

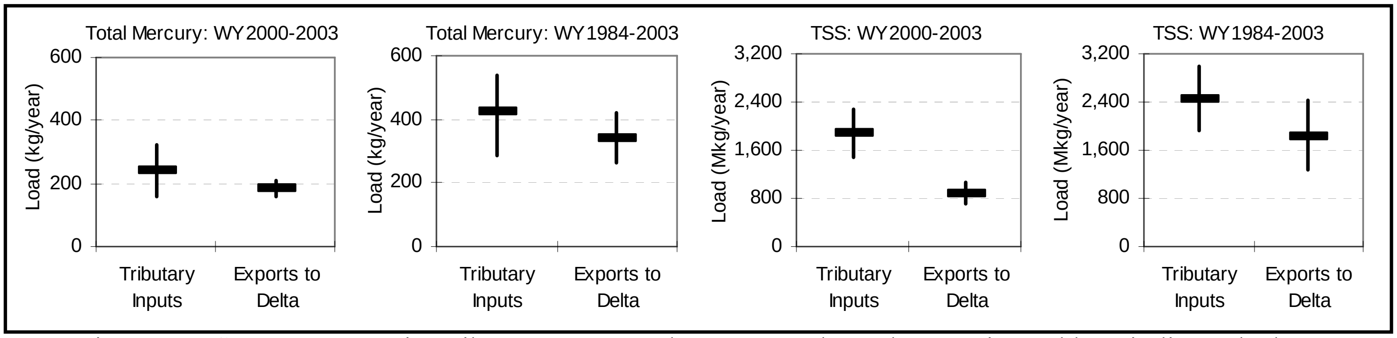

Figure 7.2: Sacramento Basin Tributary Inputs and Exports to the Delta. Horizontal bars indicate the best estimates of average annual mercury and TSS loads for each study period. Vertical bars indicate the possible range of load estimates. [This figure will be updated with corrected confidence intervals.]

TSS loads that characterize each of the watersheds. Concentration data were collected by the SRWP, DWR, USGS, CMP, and Central Valley Water Board staff (Appendix M). The water volume calculations upon which the load calculations are based are described in Appendix E. Appendix J provides graphs that illustrate time series of the available total mercury and TSS concentration data and the total mercury/flow and TSS/flow regressions described in the following pages.

Four watersheds provide more than 90% of the annual average water volume to the Sacramento River and Yolo Bypass during WY2000-2003 and WY1984-2003: Sacramento River above Colusa, Feather River, Sutter Bypass and American River. A different combination of four watersheds contributes about 90% of the annual mercury load: Sacramento River above Colusa, Cache Creek Settling Basin, Feather River, and Sutter Bypass. These same four watersheds also contribute more than 90% of the TSS load. Although the same four watersheds contribute the most mercury and TSS load, their relative ranking is different for each constituent during the different study periods. The Cache Creek Settling Basin, with a 20-year average annual mercury load of 125 kg, contributes almost as much as the upper Sacramento River watershed, while draining one of the smallest, driest watersheds in the Sacramento Basin.

Tables 7.6a and 7.6b and Figure 7.2 show the draft mass budgets for tributary inputs to the Sacramento Basin and exports from the Sacramento Basin to the Delta. The water budget balances within 4 to 7%, which indicates that all major water inputs and exports have been identified. The mass budgets will be evaluated in the context of the confidence limits of the TMDL total mercury and suspended sediment load calculations once the 95% confidence limits have been completed. The following pages describe how the total mercury and TSS loads were estimated for the Sacramento Basin tributary watersheds and the uncertainties inherent in the estimates, particularly for Sutter Bypass. For the purpose of the proposed total mercury limits (Section 8.2), it is assumed that over long periods, reductions in mercury loads in the Sacramento Basin inputs will result in equal reductions in Sacramento Basin exports to the Delta. This assumption will be reevaluated as more information becomes available.

Several studies have evaluated total mercury and suspended sediment loading in the Sacramento Basin for a variety of wet and dry years. These studies are summarized below along with the total mercury and TSS loads estimated for the Sacramento Basin tributary watersheds for this TMDL program. The results of these studies will be evaluated in the context of the confidence limits of the TMDL total mercury and suspended sediment load calculations once the 95% confidence limits have been calculated.

Total mercury and TSS concentrations for each tributary were regressed against flow to determine if correlations existed (Appendix J). The TotHg/flow and TSS/flow regressions for the American River, Cache Creek, Colusa Basin Drain, Feather River, and Sacramento River at Colusa were all statistically significant at $P<0.01$. The TotHg/flow and TSS/flow equations were used to predict the average annual loads from the tributary watersheds for WY2000-2003 and WY1984-2003 shown in Table 7.6.
LWA (2002) reported 1980-1999 annual average total mercury loads from the American River, Feather River and Sacramento River above Colusa of 15.4 kg, 55.4 kg, and 88.1 kg, respectively.

The TSS/flow regression for Putah Creek was statistically significant, but the TotHg/flow regression was not. The resulting regression equation for TSS was used to predict daily TSS concentrations. The predicted TSS concentrations were used to predict the average annual TSS loads for WY2000-2003 and WY1984-2003. Because the TotHg/flow regression was not significant at $P < 0.05$, the average total mercury concentration (Table 7.5) was multiplied by average annual flow volume to estimate WY2001-2003 and WY1984-2003 average annual mercury loads.

Daily flow data were not available for Natomas East Main Drain (NEMD) and Coon Creek watershed outflows to the Sacramento River. Average annual rainfall runoff volumes were estimated to approximate their watershed outflows (Appendix E). In addition, no concentration data were available for the outflows from these watersheds. Concentration data collected by the SRWP, USGS and City of Roseville were available for Arcade Creek near Norwood and Del Paso Heights and Dry Creek, within the NEMD watershed. Wet weather concentration data for Arcade and Dry Creeks (noted in parentheses in Table 7.5) and estimated wet weather runoff for the entire Natomas East Main Drain watershed (Appendix E) were used to develop preliminary load estimates for NEMD outflows. No total mercury or TSS concentration data were available to estimate loads in Coon Creek outflows.

The Sutter Bypass watershed includes the areas that drain into Butte Creek south of Chico and areas that drain into the Sutter Bypass between the Sacramento and Feather Rivers and south of the Sutter Buttes (Figure 7.1). In addition, flood flows from the Sacramento River upstream of Colusa are diverted into Sutter Bypass through the Moulton and Colusa bypasses; flood flows from the Sacramento River downstream of Colusa are diverted into the Sutter Bypass through the Tisdale bypass. Floodwaters from the Sacramento River also spill at several locations into the Butte Creek basin and Butte Sink, which drain to Sutter Bypass. During low flow conditions, the Sutter Bypass drains through Sacramento Slough near Karnak into the Sacramento River less than a mile upstream of the Feather River confluence. During high flow conditions, the Sacramento Slough channel is submerged and the Sutter Bypass has unchannelized flow directly into the Sacramento River. Sacramento Slough flows also are affected by Sacramento River conditions; Central Valley Water Board and DWR staff has witnessed backwater conditions on Sacramento Slough near Karnak, where the slough's flow reverses direction during high stages on the Sacramento River.

The Sutter Bypass average annual water volumes and loads illustrated in Table 7.6 were estimated using flows recorded by the DWR gage on Butte Slough near Meridian. The bypass at this location includes flows from Butte Creek and diversions from the Sacramento River made by Moulton and Colusa Weirs, which are upstream of the "Sacramento River above Colusa" sampling station, but not from Tisdale Weir or other sources that discharge to the bypass downstream of Meridian. Because only flows for WY1998-2003 are available for the gage at Meridian, the WY1998-2003 flows were used to estimate long-term average mercury and TSS loads from Sutter Bypass. WY1998-2003 represent a relatively wetter period than the WY1984-2003, hence these load estimates may overestimate the Sutter Bypass contribution to the Delta.

Total mercury and TSS concentration data were available for the Sutter Bypass at Sacramento Slough near Karnak, about 30 miles downstream of the Meridian flow gage. The data were collected between February 1996 and September 2003 during a range of flow conditions, including when Sacramento Slough was submerged. There is a flow gage located nearby; however, it was operational only during the WY1996-1998 period. In addition, it was not rated for flows above 5,200 cfs (Figure 7.3); flows exceeded the 5,200 cfs rating for the gage for extended periods during each year of the record. Therefore, the TotHg/flow and TSS/flow regressions for Sacramento Slough shown in Appendix J are based only on the samples collected when the Karnak gage recorded flows within its rating curve, most of which are low flow events. Not surprisingly, the TotHg/flow and TSS/flow regressions for Sacramento Slough were not statistically significant. Therefore, a preliminary estimate of Sutter Bypass loading was developed by multiplying water volumes recorded by the Meridian gage by the average total mercury and TSS concentrations observed at Karnak. The uncertainty of the load values was estimated by calculating the

95% confidence interval for the mean of the concentration data. This calculation does not address any uncertainty associated with using concentration data collected 30 miles downstream of the flow gage.

Tetra Tech, Inc., under contract by the USEPA, recently completed a hydrologic model for the Sacramento River watershed that Central Valley Water Board staff will use to improve flow estimates for Sutter Bypass exports. The Central Valley Water Board, SRWP, CMP and USGS all have ongoing mercury monitoring programs for locations throughout the Sacramento Basin. Results from these programs will be used to update the Sacramento Basin loading assessment as they become available.

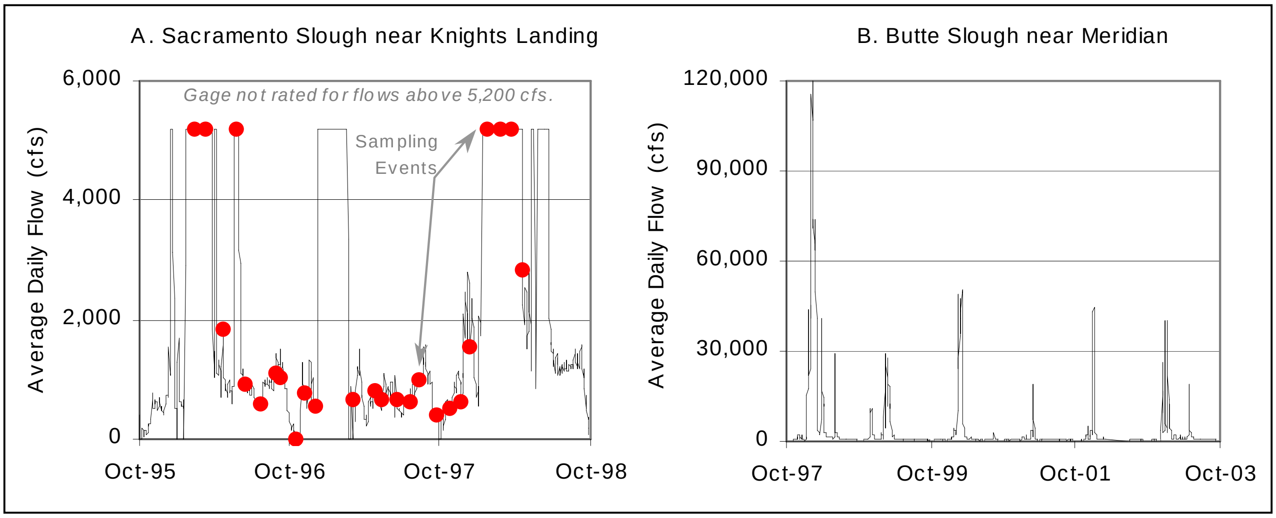

Figure 7.3: Flow Data Evaluated for Sutter Bypass.

7.1.2 Municipal & Industrial Sources

There are 20 NPDES-permitted municipal and industrial discharges to surface water in the Delta[42] (Figure 6.5). Of the 20 facilities in the Delta, five are heating/cooling and power facilities; discharges from these facilities are not considered mercury inputs to the Delta because the available information indicates that the facilities do not add notable amounts of total mercury to the water that they withdraw from Delta waterways. Information on the facilities is from the State Water Resources Control Board's Surface Water Information (SWIM) database.

Information on average flows rates for each facility was obtained from the Central Valley Water Board's discharger project files and permits. Effluent total mercury concentration data were obtained from project files and dischargers' SIP monitoring efforts.[43] Table 6.5 in Chapter 6 and Table G.1 in Appendix G

[42] It is assumed that facility discharges contain negligible amounts of suspended solids.

[43] In September 2002, the Central Valley Water Board issued a California Water Code Section 13267 order to all NPDES dischargers (except municipal stormwater dischargers) requiring the dischargers to collect effluent and receiving water samples and to have the samples analyzed for priority pollutants contained in the U.S Environmental Protection Agency's California Toxics Rule and portions of the USEPA's National Toxics Rule. This action was directed by Section 1.2 of the Policy for Implementation of Toxics Standards for Inland Surface Waters, Enclosed Bays, and Estuaries of California, also known as the State Implementation Policy (SIP), which was adopted by the State Water Resources Control Board on 2 March 2000. The SIP monitoring requires that the dischargers' mercury monitoring utilize "ultra-clean" sampling and analytical methods including Method 1669 (Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels, US EPA)

provide additional information about the facilities. Table G.1 lists the estimated annual mercury loads from each facility, which were obtained from the facility-specific average effluent concentration and average daily discharge volume multiplied by 365. It was assumed that total mercury loading from the facilities does not vary substantially between wet and dry years. This consideration will be re-evaluated as additional information becomes available. The sum of facility loads is approximately 2.4 kg/yr, about 1% of all Delta sources.

7.1.3 Urban Runoff

Approximately 60,000 acres in the Delta are urban, most of which are regulated by NPDES waste discharge requirements. Table 6.10 in Chapter 6 lists the permits that regulate urban runoff and their corresponding acreage. Figure 6.7 shows their locations. Urban areas not encompassed by a MS4 service area were grouped into a "nonpoint source" category.

Total mercury and TSS concentration data were collected by Central Valley Water Board staff and the City and County of Sacramento from several urban waterways within or adjacent to the Delta. Figure 6.8 shows the urban areas and sampling locations and Figure I.1 in Appendix I illustrates the wet and dry weather concentrations by location. Data generation by analytical methods with detection limits less than 1 ng/l began in 1996. The total mercury concentrations ranged from a dry weather low of 1.06 ng/l (Arcade Creek) to a wet weather high of 1,138 ng/l (Strong Ranch Slough). The TSS concentrations ranged from a dry weather low of less than 3 mg/l (City of Sacramento Sump 111) to a wet weather high of 1,300 mg/l (Strong Ranch Slough). A visual inspection of the total mercury and TSS data suggests that the differences between the urban watersheds are not directly related to land use. Therefore, the data were averaged by wet and dry weather for each location (Table 7.7). The averages of these location-based wet and dry weather averages are assumed to represent runoff from all urban areas in or adjacent to the Delta.

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and Method 1631 (Mercury in Water by Oxidation, Purge and Trap, and Cold Vapor Atomic Fluorescence, US EPA). The SIP monitoring requires major industrial and municipal NPDES dischargers to collect monthly samples for metals/mercury analysis, and minor industrial and municipal NPDES dischargers to collect quarterly samples. All dischargers were required to submit their effluent and receiving water data by 1 March 2003. Staff evaluated discharge data contributed prior to March 2003 to develop preliminary mercury load estimates. Staff will update this evaluation using the recently received data.

Table 7.7: Summary of Urban Runoff Total Mercury and TSS Concentrations

Urban Watershed	# of Samples	Minimum Conc. (ng/l)	Average Conc. (ng/l)	Maximum Conc. (ng/l)
TOTAL MERCURY				
DRY WEATHER				
Arcade Creek	37	1.06	8.07	34.80
City of Sacramento Strong Ranch Slough	7	3.63	18.43	84.00
City of Sacramento Sump 104	7	1.61	7.78	24.30
City of Sacramento Sump 111	7	2.16	9.59	28.96
Tracy Lateral to Sugar Cut Slough	1	7.92	7.92	7.92
Average of Location Dry Weather TotHg Averages:			**10.36**	
WET WEATHER				
Arcade Creek	14	1.73	20.90	54.30
City of Sacramento Strong Ranch Slough	13	20.10	188.32	1137.90
City of Sacramento Sump 104	14	9.94	36.72	118.42
City of Sacramento Sump 111	13	10.68	28.56	65.23
Stockton Calaveras River Pump Station	5	14.18	26.07	49.71
Stockton Duck Creek Pump Station	1	13.57	13.57	13.57
Stockton Mosher Slough Pump Station	5	9.67	14.16	17.29
Stockton Smith Canal Pump Station	4	23.17	40.97	65.87
Tracy Drainage Basin 10 Outflow	3	8.78	12.13	16.12
Tracy Drainage Basin 5 Outflow	3	7.02	12.59	20.67
Tracy Lateral to Sugar Cut Slough	3	5.44	18.10	28.45
Average of Location Wet Weather TotHg Averages:			**37.46**	
TSS				
DRY WEATHER				
Arcade Creek	28	5.0	31.7	122.0
City of Sac'to Strong Ranch Slough	6	5.0	9.3	15.0
City of Sac'to Sump 104	7	4.0	7.6	12.0
City of Sac'to Sump 111	7	1.5	6.2	11.0
Tracy Lateral to Sugar Cut Slough	1	26.5	26.5	26.5
Average of Location Dry Weather TSS Averages:			**16.26**	
WET WEATHER				
Arcade Creek	12	7.0	99.5	320.0
City of Sac'to Strong Ranch Slough	13	23.0	208.7	1300.0
City of Sac'to Sump 104	14	31.0	104.3	270.0
City of Sac'to Sump 111	11	15.7	92.4	340.0
Stockton Calaveras River Pump Station	5	26.0	94.3	264.6
Stockton Duck Creek Pump Station	1	281.3	281.3	281.3
Stockton Mosher Slough Pump Station	5	6.0	19.6	34.0
Stockton Smith Canal Pump Station	4	76.0	125.8	184.6
Tracy Drainage Basin 10 Outflow	3	81.1	136.9	236.0
Tracy Drainage Basin 5 Outflow	3	26.1	77.5	148.1
Tracy Lateral to Sugar Cut Slough	3	6.3	153.7	342.9
Average of Location Wet Weather TSS Averages:			**126.7**	

To estimate wet weather mercury and TSS loads, the average wet weather concentrations were multiplied by the runoff volumes estimated for WY2000-2003 and WY1984-2003 for each MS4 area within the Delta. To estimate dry weather mercury and TSS loads, the dry weather concentrations were multiplied by the estimated dry weather urban runoff volume. Appendix E describes the methods used to estimate wet and dry weather urban runoff from urban areas within the Delta. Wet and dry weather mercury and TSS loads were summed to estimate the WY2000-2003 average annual loadings of 2.5 kg mercury and 8.0 Mkg/yr suspended sediment, and WY1984-2003 average annual loadings of 2.6 kg mercury and 8.3 Mkg/yr TSS (Table 7.8). Uncertainty was evaluated by calculating the 95% confidence intervals for the wet and dry weather average concentrations (Table 7.1, Appendix J). Additional uncertainty may be present in the 20-year load estimates because it is unknown whether the concentration data collected between 1996 and 2003 is representative of earlier years; this uncertainty is not quantified at this time.

Urban land uses comprise a small portion of the Delta and contribute about 1% of the mercury load (Table 7.1). In contrast, approximately 320,000 acres of urban land – about 42% of all urban area within the Delta source region – are within 20 miles of the Delta boundary, about one day water travel time upstream. In addition, some of the urban watersheds outside the Delta discharge via sumps into Delta waterways. These discharges were not included in the Delta urban load estimate. As a result, the urban contribution to the Delta mercury load may be underestimated. To evaluate the potential contributions from upstream urban lands, the total mercury loadings from the two MS4 service areas with the greatest urban acreage immediately outside the Delta were estimated for the WY2000-2003 period. The sum of mercury loads from the Sacramento and Stockton MS4 areas may contribute more than 3% of loading to the Delta (Table 7.9). These loads are expected to increase as urbanization continues around the Delta.

Table 7.8: Average Annual Total Mercury and TSS Loadings from Urban Areas within the Delta

MS4 Permittee	WY2000-2003		WY1984-2003	
	TotHg Load (kg/yr)	**TSS Load** (Mkg/yr)	**TotHg Load** (kg/yr)	**TSS Load** (Mkg/yr)
City of Lathrop	0.03	0.10	0.03	0.11
City of Lodi	0.006	0.021	0.007	0.022
City of Rio Vista	0.002	0.005	0.002	0.006
City of Tracy	0.21	0.69	0.22	0.72
City of West Sacramento	0.21	0.69	0.21	0.70
County of Contra Costa	0.60	1.94	0.62	2.01
County of San Joaquin	0.41	1.33	0.42	1.38
County of Solano	0.02	0.06	0.02	0.07
County of Yolo	0.02	0.08	0.02	0.08
Port of Stockton MS4	0.05	0.15	0.05	0.16
Sacramento Area MS4	0.35	1.15	0.36	1.19
Stockton Area MS4	0.47	1.52	0.49	1.58
Urban Nonpoint Source (a)	0.31	0.99	0.10	0.33
Grand Total	**2.5**	**8.0**	**2.6**	**8.3**

(a) Urban areas not encompassed by a MS4 service area were grouped into a "nonpoint source" category within each Delta subarea.

Table 7.9: Comparison of WY2000-2003 Annual Delta Mercury and TSS Loads to Sacramento & Stockton Area MS4 Loads (a)

MS4 Service Area (Urban Acreage)	**Water Volume** (acre-feet) (b)	**TotHg Load** (kg/year)	**TSS Load** (Mkg/yr)
Sacramento MS4 Urban Total	174,593	6.85	22.31
Stockton MS4 Urban Total	25,304	0.97	2.05
Total Delta Inputs (c)	19,425,472	222	1,085
Stockton & Sacramento Urban Runoff as % of Total Delta Inputs	**1.0%**	**3.5%**	**2.2%**

(a) The Sacramento and Stockton Area MS4s are the two MS4 service areas with the greatest urban acreage immediately outside the Delta, with urban land use areas of 154,050 and 24,901acres, respectively.
(b) Refer to Appendix E for urban runoff volume estimates for wet and dry weather, which were summed to estimate the annual average water volumes shown above.
(c) These values represent the sum of all tributary and within-Delta total mercury and TSS sources shown in Table 7.1.

7.1.4 Atmospheric Deposition

Atmospheric deposition of mercury has not yet been measured within the Delta. Table 7.10 and Figure 7.4 illustrate the wet deposition data available for northern and central California. Volume-weighted average total mercury concentrations ranged from 4.1 ng/l at Covelo to 13 ng/l at Sequoia National Park. To estimate wet deposition, the volume-weighted average concentration observed at the North Bay/Martinez station (7.4 ng/l) was used because the station is closest to, and typically upwind of, the Delta. The other stations are separated from the Delta by mountainous watershed divides and may not be as representative of conditions in the Delta.

Total mercury loading from precipitation on surface water in the Delta (direct deposition) was estimated by multiplying the average mercury concentration in North Bay/Martinez rainwater (Table 7.10) by the average rainfall volume to fall on Delta water surfaces during WY2000-2003. Loading from runoff of mercury-contaminated rain falling on land (indirect deposition) was estimated by multiplying the average mercury concentration in rainwater by the estimated runoff volume for WY2000-2003. Runoff from urban areas was not included because it is inherently incorporated in the estimates for loading from urban runoff described in Section 7.1.3. Appendix E describes the method used to estimate rainfall runoff volumes for the Delta. Table 7.11 lists the estimated mercury loads from direct and indirect wet deposition. Wet deposition contributes approximately 1% of all mercury entering the Delta (Table 7.1).

There are several uncertainties inherent in the estimates of atmospheric deposition of mercury in the Delta, including but not limited to: (a) the concentration of mercury in rainfall and dry deposition loading in the Delta and its tributary watersheds; (b) the appropriate runoff coefficient to use; and (c) the amount of mercury deposited from local air emissions. These uncertainties do not have a substantial impact on the Delta total mercury budget described in Tables 7.1 because even a tenfold increase in loading from atmospheric deposition would be insubstantial when compared to the loading to the Delta from the

Table 7.10: Summary of Available Data Describing Mercury Concentrations in Wet Deposition in Northern and Central California.

Study (a)	**Station**	**Volume-Weighted Average TotHg Conc.** (ng/l)	**# of Samples**	**Collection Period**
San Francisco Bay Atmospheric Deposition Pilot Study (SFBADPS) (b)	North Bay	7.4	14	Aug. 1999 – Jul. 2000
	Central Bay	6.6	16	
	South Bay (c)	9.7	29	
National Atmospheric Deposition Program (NADP) Mercury Deposition Network (MDN)	San Jose (c)	10	86	Jan. 2000 – Dec. 2003
	Sequoia National Park (d)	13	5	Jul. 2003 – Dec. 2003
	Covelo (e)	4.1	60	Dec. 1997 – Sep. 2000

(a) Sources: NADP MDN – Sweet, 2000; NADP, 2004. SFBADPS – SFEI, 2001.
(b) The North Bay, Central Bay, and South Bay sites are located at Martinez, Treasure Island and Moffett Federal Airfield/NASA Ames Research Center near San Jose, respectively.
(c) In addition to being part of the SFBADPS, the South Bay site also became one of the NADP MDN stations. Co-location of mercury wet deposition sampling under the MDN/NADP with the Pilot Study at the South Bay site began in January 2000 and resulted in ten replicate field precipitation samples.
(d) Sequoia National Park is in the Sierra Nevada Mountains to the southeast of Fresno in the Tulare Basin, which is south of the San Joaquin Basin.
(e) Covelo is ~150 miles north of San Francisco Bay in the Coast Range.

Table 7.11: Average Annual Total Mercury Loads from Wet Deposition for WY2000-2003 (a)

Period/Deposition Type (b)	**Water Volume** (acre-feet) (c)	**TotHg** (kg/year)
Direct Deposition	93,498	0.85
Indirect Deposition	154,100	1.41
TOTAL	247,598	2.26

(a) The volume-weighted average concentration observed in the North Bay/Martinez (7.4 ng/l, Table 7.10) was used to estimate total mercury loading to the Delta.
(b) Direct deposition results from mercury-contaminated rain falling on Delta surface waters. Indirect deposition results from runoff of mercury-contaminated rain falling on land surfaces in the Delta. Runoff from urban areas was not included because it is inherently incorporated in the estimates for loading from urban runoff described in Section 7.1.3.
(c) Refer to Appendix E for a description of the methods used to estimate rainfall runoff volumes.

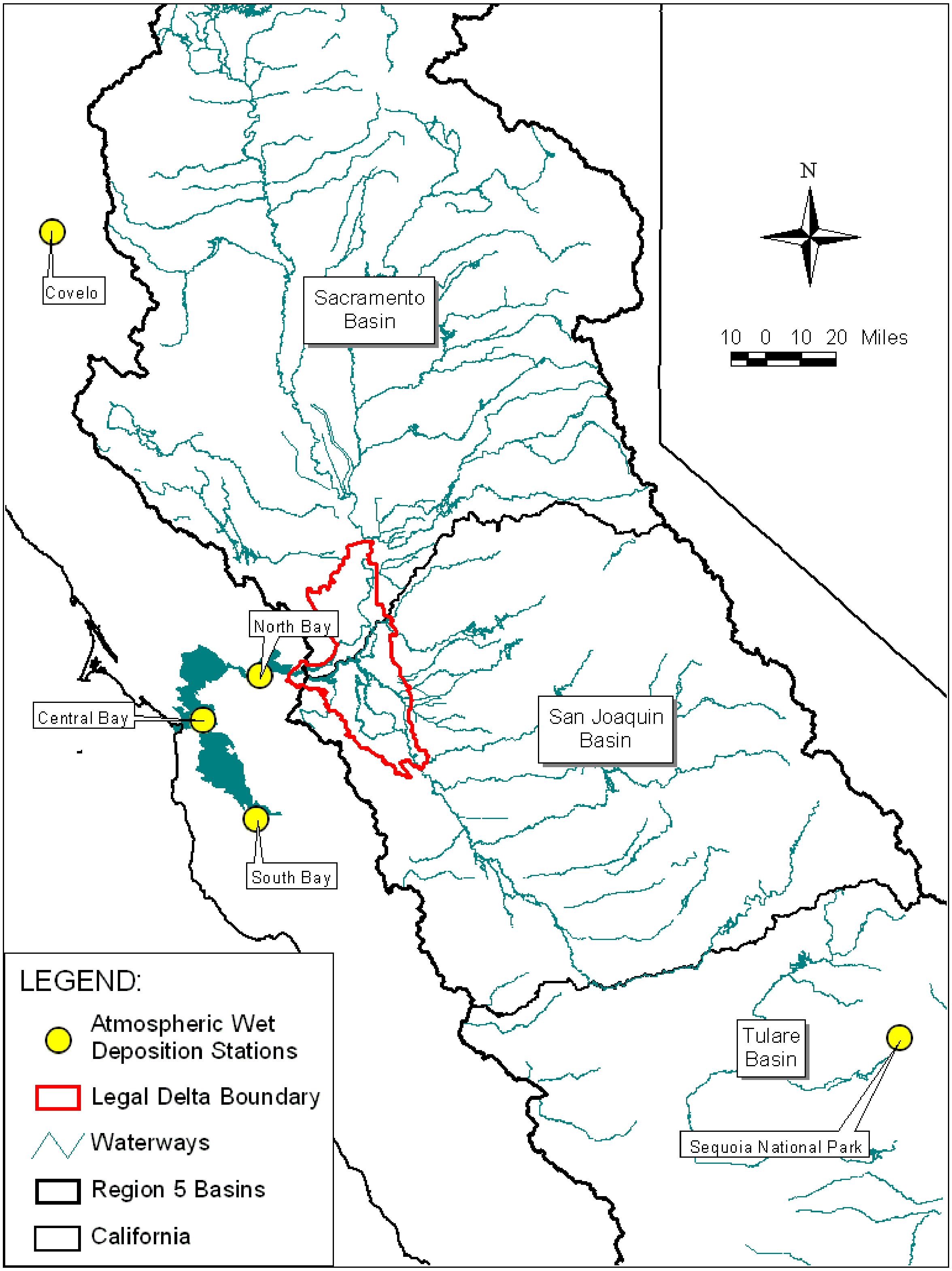

Figure 7.4: Wet Deposition Total Mercury Sampling Locations in Northern and Central California

Sacramento River and Yolo Bypass. However, these uncertainties have important implications for determining future mass budgets for the tributary watersheds because of their immense acreage.

Mercury loading from dry deposition was not estimated because of the level of uncertainty with respect to the amount of dry deposition that is entrained in runoff. SFEI (2001b) estimated that about 4.5 times more mercury is deposited on an annual basis in dry deposition than in wet deposition in San Francisco Bay. In addition, it was assumed for the wet deposition load estimates listed in Table 7.11 that total mercury in atmospheric deposition has a similar runoff coefficient as water. However, mercury may be more or less easily transported than water once it comes in contact with land surfaces. Runoff coefficients are a function of meteorology, land use characteristics, slope, size and soil characteristics of the watershed (Tsiros, 1999). Dolan and others (1993) estimated that roughly 10% of the mercury falling in the Lake Superior watershed entered the lake. Quemerais and others (1999) determined that about 12% of the atmospheric mercury deposited in the St. Lawrence River watershed ran off. Mason and others (1994) estimated that about 30% of atmospheric deposition was reaching Swedish and mid continental American lakes in overland flow. SFEI (2001b) used a runoff coefficient of 32% for San Francisco Bay. The Delta TMDL analyses employed a range of runoff coefficients based on land uses that ranged from 13% for forested upland areas to 70% for industrial/commercial areas. Dr. Gill and other researchers from Texas A&M University are currently conducting a study as part of the ongoing CALFED-funded project (ERP-02-C06-B) to measure total mercury in atmospheric deposition at sites in the Sierra Nevada Mountain Range, Coastal Range, and the Delta. The study should be completed and a report prepared by the fall of 2006.

In an attempt to identify local – and therefore potentially controllable – sources of mercury in atmospheric deposition in the Delta and its tributary watersheds, mercury loads emitted by facilities that report emissions to the California Air Resources Board (ARB) were reviewed. The ARB Emission Inventory Branch tracks mercury loading in air emissions in its California Emission Inventory Development and Reporting System database. ARB staff provided a database describing facilities that reported mercury emissions in 2002. Appendix K provides a summary of the types of facilities in each watershed and their estimated loads. The data indicate that almost 10 kg of mercury were released in the Delta by sugar beet facilities, electric services, paper mills, feed preparation, and rice milling. Cement and concrete manufacturing facilities and crematories in the Delta's tributary watersheds appear to have relatively high mercury emissions. These loads are not incorporated in the mass budgets because their deposition rates are not known. Local air emissions of mercury warrant additional research.

7.1.5 Other Potential Sources

Loading from Delta soils has not been evaluated. More than 70% of Delta lands have agricultural land uses and many of the urban areas in the Delta were once agricultural. Farming began in the Delta in 1849, about the same time that gold mining began in the Sierra Nevada Mountains (DWR, 1995). In 1861, the California legislature authorized the Reclamation District Act, which allowed drainage of Delta swampland and construction of levees; the extensive Delta levee system was mostly built between 1869 and 1880 (DWR, 1995). By 1852, hydraulic mining was the most common method for mining the placer gold deposits in the Sierra Nevada (Hunerlach *et al*., 1999) and continued until the Sawyer Decision outlawed the practice in 1884. Hydraulic gold mining resulted in the deposition of large amounts of silt and sand in Delta channels and upstream rivers (DWR, 1995). Much of these deposits may be contaminated with mercury used to amalgamate the gold. Therefore, some levees and Delta islands may have been constructed with mercury-contaminated sediment.

Barley and other grains have historically been common rotational crops in the Delta (Weir, 1952), and the seeds were treated with mercury-based fungicides before sowing (LWA, 2002). It is not known how much mercury was used in the Delta, but up to 38,000 kg of mercury may have been added in fungicides in the Sacramento Valley between 1921 and 1971 (LWA, 2002). Mercury is no longer used as an active ingredient in any pesticides (DPR, 2002).

Mercury has been measured in 26 soil samples in the Delta source region, mostly from agricultural fields (Bradford *et al.*, 1996). One sample was collected in the eastern Delta near White Slough north of Stockton (0.27 mg/kg) and five samples were collected within 10 miles of the Delta boundary (0.25, 0.34, and three results <0.2 mg/kg). There was no relationship between soil mercury levels and location and soil type. Some of the mercury concentrations were elevated and may warrant additional monitoring.

7.2 Total Mercury and TSS Losses

The following were identified as total mercury losses from the Delta: flow to San Francisco Bay, water diversions to south of the Delta, removal of dredged sediments, and evasion. Table 7.12 lists the total mercury and TSS load estimates for these losses. The following sections describe the total mercury and TSS concentration data available for the losses and identify some of the data gaps and uncertainties associated with the load estimates.

Table 7.12: Average Annual Total Mercury and TSS Losses for WY2000-2003 and WY1984-2003. (c)

	WY2000-2003				**WY1984-2003**			
	TotHg		**TSS**		**TotHg**		**TSS**	
	(kg/yr)	% of All Inputs	(Mkg/yr)	% of All Inputs	(kg/yr)	% of All Inputs	(Mkg/yr)	% of All Inputs
Outflow to San Francisco Bay [X2] (a)	83 ±28	43%	450 ±##	52.1%	201 ±68	65%	1,202 ±381	75
Dredging (b)	57 ±##	30%	304 ±##	35.2%	57 ±##	19%	304 ±##	19
Evasion	30 ±##	16%	*not applicable*		30 ±##	10%	*not applicable*	
State Water Project	12 ±##	6.2%	47 ±##	5.4%	9.6 ±##	3.1%	38 ±##	2.4
Delta Mendota Canal	11 ±##	5.7%	62 ±##	7.2%	10.3 ±##	3.3%	60 ±##	3.7
Sum of Losses	**193 ±##**	**100%**	**863 ±##**	**100%**	**308 ±##**		**1,604 ±##**	

(a) Source: Leatherbarrow & others, 2005. The X2 TotHg and TSS loads listed for WY1984-2003 are based on the average annual load calculations for WY1995-2003.
(b) The confidence intervals for the evasion mercury and dredging sediment load estimates were not evaluated.
(c) The 95% confidence limits will be calculated using a method developed in consultation with UC Davis that will be described in Appendix J once completed.

7.2.1 Outflow to San Francisco Bay

Estimates of total mercury and sediment loading from the Delta to San Francisco Bay are critical components of the Delta mercury TMDL for two reasons. First, outflow to San Francisco Bay is the primary export from the Delta and must be accurately measured to determine whether the Delta is a net source or sink for mercury and sediment. Second, the San Francisco Bay mercury TMDL assigned the Central Valley a mercury load allocation of 330 kg/yr that must be met either at Mallard Island or by a 110 kg reduction in mercury sources to the Delta (Section 2.4.2.3). Four studies have evaluated sediment and mercury loading rates to the San Francisco Bay (Table 7.13). These studies are summarized below. The results of these studies will be evaluated in the context of the confidence limits of the TMDL total mercury and suspended sediment load calculations once the 95% confidence limits have been completed. Comparison of the results is complicated by the fact that all estimates were done by different methods and for different groups of water year types. Greater flux rates are thought to occur in wet years.

Central Valley Water Board staff evaluated TSS and mercury levels in Central Valley outflows to San Francisco Bay by collecting samples at X2. Figure 6.9 in Chapter 6 illustrates a typical location of X2. Central Valley Water Board staff conducted monthly aqueous total mercury and TSS sampling at X2 from March 2000 to September 2001 (Foe, 2003) and from April 2003 to September 2003. Table 7.14 and Figures J.1 through J.8 summarize the available total mercury and TSS concentration data for the Delta's major exports. Total mercury concentrations at X2 averaged 17.3 ng/l and ranged from 3.9 ng/l to 49.2 ng/l. The TSS concentrations at X2 averaged 60 mg/l and ranged from 27 mg/l to 168 mg/l. Net daily Delta outflow was obtained from the Dayflow model (Appendix E). Total mercury and TSS concentrations at X2 were regressed against Delta outflow to determine whether either could be predicted from flow (Appendix J). Neither regression was significant. Therefore, average mercury and TSS concentrations were multiplied by average annual flow volumes for WY2000-2003, WY1984-2003 and WY1995-2005 to estimate annual loads (Table 7.13). Foe (2002) used a similar method to estimate monthly loads between March 2000 and September 2001, a relatively dry period. He estimated annual sediment and mercury loads for WY2001 of 473 Mkg and 122 kg, respectively (Table 7.13).

The average Central Valley total mercury load cited in the San Francisco Bay TMDL (Johnson & Looker, 2004) was based on research available at the time of its development (McKee & Foe, 2002; McKee *et al.*, 2001; Foe, 2003). The average annual total mercury load (440 kg) was estimated by multiplying suspended sediment flux measured at Mallard Island using an optical back scatter meter (OBS)[44] during WY1995-2000 (McKee & Foe, 2002; McKee *et al.*, 2001) by the mercury concentrations in suspended sediment measured at X2 during March 2000 through September 2001 (Foe, 2003). The sediment flux value was corrected for tidal dispersion (McKee & Foe, 2002; McKee *et al.*, 2001).

Leatherbarrow, McKee and others (2005) updated the mercury load estimates cited in the San Francisco Bay mercury TMDL report using mercury concentration data collected at Mallard Island between January 2002 and May 2003, an effort that focused on high flows and the influence of tide and salinity on mercury. The updated mercury load for WY1995-2000 (270 kg) is a 40% decrease from the earlier TMDL estimate (440 kg). The authors found that the origin of water – predominantly from upstream during floods or a mixture of water from the Delta and Suisun Bay during low flows – influenced the particulate mercury concentration in the water column. The increased concentrations on incoming tide may result from erosion of sediment and associated mercury from Suisun and Grizzly Bays. Because the updated load estimate is based on mercury data collected during a relatively low flow period that did not experience substantial flood inputs from the Yolo Bypass, the authors expect the long-term estimates to change as more information for larger flood events becomes available.

[44] The Mallard Island OBS instrument was calibrated with water samples collected at the same point and analyzed in a laboratory for suspended sediment concentration.

Table 7.13: Estimates of Delta Loading to San Francisco Bay

Study (a)	**Sampling Location**	**Period**	**Average Water Year Hydrologic Index** (b)	**Average Annual Water Volume** (M acre-feet) (c)	**Average Annual TotHg Load** (kg)	**Average Annual TSS Load** (Mkg)	**TotHg:TSS** (mg/kg)
Delta Mercury TMDL Program X2 Calculations	X2 (f)	WY2000-2003	7.3	12	258 ±##	893 ±##	0.30
		WY1984-2003	7.8	17	363 ±##	1,257 ±##	
		WY1995-2000	11.0	31	660 ±##	2,289 ±##	
Foe (2002)	X2 (d)	WY2001 (d)	5.8	7.2	122	473	0.25
S.F. Bay Mercury TMDL (2004)	Mallard Island	WY1995-2000	11.0	31	440 ±100	1,600 ±300	0.26 ±0.075
Leatherbarrow & others (2005) (e)	Mallard Island	WY1999-2003	7.8	18	97 ±33	524 ±166	0.11 / 0.29 (e)
		WY2000-2003	7.3	12	83 ±28	450 ±140	
		WY1995-2000	11.0	31	270 ±91	1,600 ±510	
		WY1995-2003	9.6	24	201 ±68	1,202 ±381	

(a) Sources: this report; Leatherbarrow & others, 2005; Johnson & Looker, 2004; Foe (CALFED), 2002.
(b) DWR calculated a hydrologic index for the Sacramento Valley (Appendix E). "Normal" hydrologic conditions for the Sacramento Valley are represented by an index value of 7.8, "wet" is ≥9.2, "dry" is between 5.4 and 6.5, and "critical dry" is ≤5.4.
(c) All average annual water volumes are from the Dayflow model results for Delta outflows to San Francisco Bay.
(d) Foe's 2002 CALFED study estimated monthly total mercury and TSS loads for March 2000 through September 2001, but did not include load estimates for November 2000. November total mercury and TSS loads for WY2001 were estimated by averaging the loads for October and December 2000.
(e) Leatherbarrow and others (2005) extrapolated total mercury loads from suspended sediment flux and suspended sediment mercury levels by adjusting for tidal dispersion and salinity, where for conductivity < 2 mS/cm, TotHg:TSS is 0.11 mg/kg, and conductivity > 2 mS/cm, TotHg:TSS is 0.29 mg/kg. Central Valley Water Board staff averaged the annual load estimates provided by Leatherbarrow and others (2005) for WY1995 through 2003 to estimate average annual loads for the periods that correspond to the San Francisco Bay mercury TMDL study period (WY1995-2000) and the Delta mercury TMDL WY2000-2003 study period.
(f) The 95% confidence limits will be calculated using a method developed in consultation with UC Davis that will be described in Appendix J once completed. Caution should be used in the comparison of the WY1995-2000 and WY1984-2003 load estimates to other studies because

Table 7.14: Summary of Total Mercury and TSS Concentration Data for X2

	# of Samples (a)	**Min. Conc.**	**Ave. Conc.**	**Median Conc.**	**Max. Conc.**
TotHg (ng/l)	21	3.95	17.29	11.00	49.20
TSS (mg/l)	22	27.0	60.0	42.0	168.0

(a) Sampling at X2 took place between March 2000 and September 2003.

7.2.2 Exports South of Delta

Water diversions to the southern Central Valley and southern California account for approximately 12% of the total mercury and TSS exports from the Delta. Delta Mendota Canal (DMC) and State Water Project (SWP) exports were evaluated by collecting water samples from the DMC canal off Byron highway (County Road J4) and from the input canal to Bethany Reservoir, respectively. Bethany is the first lift station on the State Water Project canal system and is about one mile south of Clifton Court Forebay in the Delta (Figure 6.9).

Central Valley Water Board staff collected monthly total mercury and TSS samples from the DMC and SWP between March 2000 and September 2001 (Foe, 2003) and between April 2003 and 2004. Table 7.15 and Appendix J summarize the data. DMC and SWP exported water volumes were obtained from the Dayflow model (Appendix E). Total mercury and TSS concentrations were regressed against daily flow at both sites to determine whether concentrations could be predicted from flow (Appendix J). The regressions were not significant. Therefore, average mercury and TSS concentrations were multiplied by the WY2000-2003 average annual water volumes to estimate loads (Table 7.12). Central Valley Water Board staff is continuing to collect additional information at both locations. The data should be available in the fall of 2006.

Table 7.15: Summary of Total Mercury and TSS Concentration Data for Exports South of the Delta

Site	# of Samples (a)	Min. Conc.	Ave. Conc.	Median Conc.	Max. Conc.
Delta Mendota Canal					
TotHg (ng/l)	21	1.85	3.48	3.41	5.96
TSS (mg/l)	22	9.2	20.1	18.9	36.0
State Water Project					
TotHg (ng/l)	19	0.99	3.02	2.23	7.17
TSS (mg/l)	21	4.4	12.0	8.2	59.0

(a) Sampling of these exports took place between March 2000 and September 2003.

7.2.3 Dredging

Sediment is dredged from the Delta to maintain the design depth of ship channels and marinas. Dredge material is typically pumped to either disposal ponds on Delta islands or upland areas with monitored return-flow. Table 6.18 provides details on recent dredge projects in the Delta and Figure 6.9 shows their approximate location. The Sacramento and Stockton deep water channels have annual dredging programs; the locations dredged each year vary. Dredging occurs at other Delta locations when needed, when funds are available, or when special projects take place. Approximately 533,000 cubic yards of sediment are removed annually with about 200,000 cubic yards from the Sacramento Deep Water Ship Channel and about 270,000 cubic yards from the Stockton Deep Water Channel. Other minor dredging projects, mostly at marinas, remove an additional 64,000 cubic yards per year.

The amount of mercury removed annually by dredging was estimated by multiplying dredge volume at each project site by its average mercury concentration. Average mercury concentrations in the sediment for the project sites range from 0.04 to 0.44 mg/kg (dry weight). Two critical assumptions were made to calculate the total mercury removed from the Delta by dredging projects:

- Water content of the dredged material is 100% (50% water and 50% sediment by weight) (USACE, 2002); and
- There are about 570 kilograms of dry sediment per cubic yard of wet dredged material based on relative densities of water and sediment (Weast, 1981; Elert, 2002).

The following uses the Stockton Deep Water Channel dredging project information to illustrate how mercury loads in dredge materials were estimated.

<u>Equation 7.1</u>:

TotHg Removed by Dredging Project = Volume * Concentration

23 kg/year = [(270,000 cy/year) * (570 kg)] * (0.15 mg/kg)

Where: Volume = Volume of wet dredge material (cubic yards) * 570 kg/cy (to convert to dry sediment volume)

Concentration = Dry sediment total mercury concentration

The uncertainty of the mercury load values associated with each project was estimated by calculating the 95% confidence interval for the mean of the mercury concentration data for each project. As indicated in Table 6.18, the uncertainty associated with the amount of mercury removed by dredging in the Sacramento Deep Water Ship Channel is particularly substantial (±446 kg), as a consequence of its calculation being based on only two sample results (0.68 and 0.061 mg/kg mercury) that have a tenfold range.

Central Valley Water Board waste discharge requirements regulate sediment disposal and effluent from the disposal sites. The effluent limit for total mercury is 50 ng/l. For sites that have discharges to surface waters within the Delta, the total mass of mercury returned to the Delta is approximately 0.01 kg/year (Table 6.18).

The calculations indicate that annual dredging in the Delta removes about 57 ±451 kg of total mercury and 349 Mkg of sediment. This accounts for approximately 30% of the total mercury and 35% of sediment exports (Table 7.12). Central Valley Water Board staff will continue evaluation of the uncertainty in this estimate as more data becomes available.

7.2.4 Evasion

The loss of elemental mercury from water surfaces can be estimated on the basis of measured dissolved gaseous elemental mercury concentrations, atmospheric mercury concentrations, and estimated wind speeds (Conaway *et al.*, 2003). Conaway and others (2003) estimated summer and winter evaporation rates for San Francisco Bay. The Bay has a surface area of approximately 1.24×10^9 square meters (~306,400 acres) and is estimated to lose about 190 kg/yr of mercury to the atmosphere (Johnson & Looker, 2004). Similar estimates are not available for the Delta. However, an ongoing CALFED-funded project (ERP-02-C06-B) is attempting to measure evasion in the Delta. The results should become available in the winter of 2006. To obtain a preliminary estimate of evasion in the Delta, it was assumed that the loss rate would be proportional to that of San Francisco Bay. The mercury lost from the Bay's surface (190 kg/year) was multiplied by the ratio of the water surface area of the Delta to that of the Bay (0.16). The result is an evasion rate for the Delta of about 30 kg/yr, about 16% of all Delta mercury losses.

Dr. Gill and other researchers are currently conducting a study as part of an ongoing CALFED-funded project (Proposal ERP-02-C06-B) to measure atmospheric flux of dissolved gaseous mercury from the Delta. Once the results of their study are available, the evasion load will be re-calculated.

7.2.5 Other Loss Pathways

Wright and Schoellhamer (2005) indicated that a substantial portion (~67%) of annual sediment inflow to the Delta between 1999 and 2002 may have been deposited in the Delta. The amount of sediment removed by regular dredging operations in ship channels and marinas (see Section 7.2.3) indicates that substantial deposition takes place in some areas of the Delta. Annual deposition in channel point bars and banks and in flooded wetlands was not estimated. Insufficient information presently exists to determine whether the Delta experiences net erosion or deposition over a longer period.

7.3 Total Mercury & Suspended Sediment Budgets

Delta mercury and suspended sediment assessments rely on a box model approach to approximate mass balances. Mass balances are useful because the difference between the sum of known inputs and exports is a measure of the uncertainty of the load estimates and of the importance of other unknown processes. Table 7.16 and Figure 7.5 show the Delta's average annual water, total mercury and TSS budgets for WY2000-2003, based on the values presented in Tables 6.1, 7.1, and 7.12.

Table 7.16: Water, Total Mercury & TSS Budgets for the Delta for WY2000-2003.

	Water Volume (M acre-feet/yr)	**Total Mercury** (kg/yr)			**TSS** (Mkg/yr)		
		Lower	**Average**	Upper	Lower	**Average**	Upper
Inputs	19.38	*tbd*	222	*tbd*	*tbd*	1,085	*tbd*
Exports	19.04	*tbd*	191	*tbd*	*tbd*	863	*tbd*
Inputs - Exports	**0.34**		**31**			**222**	
Exports ÷ Inputs	**98%**		**86%**			**80%**	

The sum of WY2000-2003 water inputs and exports balance within 2%, indicating that all the major water inputs and losses have been identified. In contrast, the mercury and TSS budgets do not balance. The best estimates of mercury and TSS loads indicate exports are about 80% of inputs. The mass budgets will be evaluated in the context of the confidence limits of the TMDL total mercury and suspended sediment load calculations once the 95% confidence limits have been completed to determine whether uncertainty in the load calculations may result in the deficit balance.

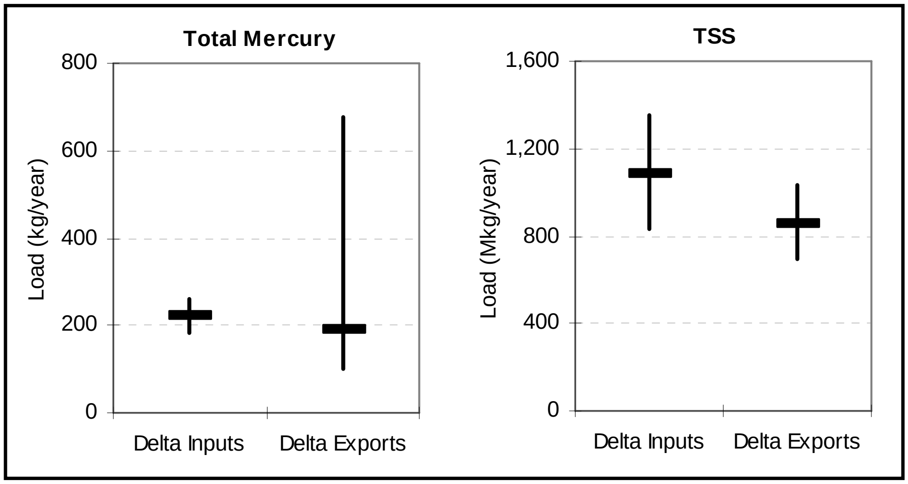

Figure 7.5: Total Mercury & TSS Inputs to and Exports from the Delta.
Horizontal bars indicate the best estimates of average annual mercury and TSS loads for WY2000-2003.
Vertical bars indicate the possible range of load estimates.
[This figure will be updated with corrected confidence intervals.]

Quantifying loading from the Central Valley to the San Francisco Bay and understanding whether the Delta is erosional or depositional is critical for developing a strategy to (1) efficiently reduce the stock of new mercury to be methylated in the Delta and (2) to meet San Francisco Water Board staff's proposed total mercury allocation for the Central Valley. Quantifying the uncertainty in the load estimates (e.g., the 95% confidence limits) is critical to the assessment of the effectiveness of control actions taken to reduce total mercury loading to the Delta and of compliance with San Francisco Water Board's allocation.

The TMDL for San Francisco Bay assigned the Central Valley a five-year average total mercury load allocation of 330 kg/yr at Mallard Island or a decrease of 110 kg/yr in mercury sources to the Delta (Section 2.4.2.3). The variety of study results for total mercury loading from the Central Valley to San Francisco Bay illustrated in Table 7.13 demonstrate the importance of both the method used to estimate loads and the water year type for which they are made. It may be more accurate to assess compliance with the San Francisco TMDL by focusing on loads entering the Delta because of the difficulty in measuring loads removed by Delta outflow, dredging, and deposition. As described in Section 7.2.1, the Sacramento Basin is the primary source of mercury in Delta outflows to San Francisco Bay. This TMDL estimated average annual Sacramento Basin loads to the Delta for WY1984-2003 of approximately 344 kg mercury and 1,849 Mkg sediment. The WY1984-2003 period had a mix of wet and dry water years similar to the 98-year water record for the Sacramento Basin. Mercury loads entering the Delta from the Sacramento Basin during this 20-year period were about 22% less than Delta outflows estimated by the San Francisco Bay TMDL for WY1995-2000[45] while sediment loads were about 16% higher. The Sacramento Basin and Delta total mercury outflows will be further evaluated against the San Francisco

[45] The San Francisco Bay TMDL sediment target applies to particulate not total mercury. Particulate mercury is defined as total minus filter-passing mercury. Filter-passing mercury concentrations at X2 in the Delta average 4% of the total concentration, demonstrating that most of the mercury exiting the Delta is attached to particles (Foe, 2003). Therefore, the WY1984-2003 loads may slightly overestimate particulate loads.

Bay allocation in the context of their 95% confidence limits once the confidence limits have been completed.

7.4 Evaluation of Suspended Sediment Mercury Concentrations & CTR Compliance

The evaluation of mercury contamination on suspended sediment particles for each Delta input and export site – in tandem with the source load analyses described in Sections 7.1 and 7.2 – is used to identify locations for possible remediation. The recommended total mercury control strategy described in Chapter 8 focuses on sources that have large mercury loadings and suspended sediment with high mercury concentrations, the premise being that it will be more cost effective to focus cleanup efforts on watersheds that export large amounts of mercury-contaminated sediment. In addition, the strategy incorporates source reductions needed to meet and maintain compliance with the CTR throughout the Delta.

7.4.1 Suspended Sediment Mercury Concentrations

Table 7.17 lists mercury to TSS ratios for Delta sources and export sites calculated using three different methods. The three approaches provide a range of particulate mercury contamination fluxing past a site. First, the ratios (in mg/kg) were estimated by dividing average annual mercury load (kg) by average annual TSS load (Mkg). This relationship is the preferred approach for stations with statistically-significant total mercury to flow and TSS to flow relationships because it provides a flow-weighted estimate. The ratio was also estimated from the slope of the regression between mercury and TSS using paired samples. The least acceptable method is to take the median of the mercury to TSS ratios computed from individual paired samples. The median value tends to overemphasize low and moderate flows (the flows sampled most often) and not high flow events, which transport the majority of the suspended sediment and mercury. All three methods slightly overestimate particulate mercury (the focus of the San Francisco Bay sediment goal of 0.2 mg/kg) because none subtract the dissolved fraction from the total mercury concentration.

7.4.1.1 Mercury to TSS Ratios for Delta Outflows to San Francisco Bay

The San Francisco TMDL for mercury adopted a sediment objective of 0.2 mg/kg (Johnson & Looker, 2004). Mercury contamination on sediment in Delta outflow to San Francisco Bay averaged between 0.18 mg/kg and 0.30 mg/kg (Table 7.17). The low value is from Leatherbarrow and others' (2005) estimate for total mercury and suspended sediment loads at Mallard Island. The ratio of 0.18 may underestimate the average concentration on suspended particles because it is less than all values presently being measured by Central Valley Water Board staff in midchannel off Mallard Island (Foe, personal communication). In contrast, the ratio of 0.3 mg/kg is from measurements taken in mid channel at X2 (Foe, 2003). The 0.3 ratio may overestimate the degree of mercury contamination being exported from the Central Valley to San Francisco Bay. The 0.3 ratio is similar to suspended sediment concentrations of 0.33 mg/kg in San Pablo Bay (Schoellhamer, 1996) and bulk surficial sediment concentrations in Suisun Bay of 0.3 to 0.35 ppm (Slotton *et al.*, 2003; Heim *et al.*, 2003) but higher than most suspended sediment values for the lower Sacramento River (0.17 to 0.23 mg/kg) or Yolo Bypass (0.16 to 0.19 mg/kg at Prospect Slough, Table 7.17). Hornberger and others (1999) report that the mercury concentration of sieved surficial sediment (<0.64 µm) in a core from Suisun Bay was 0.3 mg/kg but increased to 0.95

mg/kg at a depth of 30 cm. The mercury enriched zone persisted to a depth of about 80 cm before declining to a baseline concentration of 0.06 ±0.01 mg/kg. The increased mercury concentration at 30-cm was ascribed to deposition of mercury contaminated gold tailings. The suspended sediment values for the Delta in Table 7.17 are also consistent with bulk surficial sediment concentrations (0.15 to 0.2 mg/kg) reported for the Delta by Slotton and others (2003) and Heim and others (2003).

No current information is available on erosion rates in Suisun and Grizzly Bays but both embayments were eroding at the rate of 528 Mkg per year between 1942 and 1990 (Cappiella *et al.*, 2001). Therefore, a hypothesis is that the elevated mercury contamination on particles at X2 and at Mallard is the result of continuing erosion from Suisun Bay and possibly San Pablo Bay. Both embayments are within the legal jurisdiction of the San Francisco Water Board and are part of their recently adopted TMDL for mercury. Central Valley Water Board staff recommends that compliance with the San Francisco Bay mercury allocation for the Central Valley be assessed upstream of Mallard Island to avoid problems with possible contamination from continuing erosion of Suisun Bay.

7.4.1.2 Mercury to TSS Ratios for Delta Inputs

Urban runoff and almost all Delta inputs have mercury to TSS ratios greater than 0.2 mg/kg (Table 7.17). Exceptions are the San Joaquin River, Ulatis Creek, and Yolo Bypass. An evaluation of the tributary sources to the Sacramento River and Yolo Bypass indicates that all but the Sacramento River above Colusa, Sacramento Slough and Colusa Basin Drain have ratios greater than 0.2 mg/kg. A comparison of Table 7.5 and Table 7.17 indicates that several tributaries in the Sacramento Basin have high mercury to TSS ratios and large loads of total mercury. Cache Creek and Feather River have high ratios and high average annual total mercury loads. This makes both attractive candidates for mercury control programs. The American River and Putah Creek also have high ratios but comparatively smaller mercury loads. In contrast, the Sacramento River above Colusa and Sacramento Slough (which receives most of its annual flows when upper Sacramento River flood waters are diverted to Sutter Bypass) have ratios comparable to background levels (0.10 and 0.14 mg/kg, respectively) but high mercury loads. This is because both are transporting large amounts of sediment.

The 2002 LWA report noted a similar pattern in its evaluation of median mercury to TSS ratios for the Sacramento Basin. Suspended sediment mercury concentrations between 0.03 and 0.19 mg/kg may result from a combination of erosion of background soils and atmospheric deposition from regional and global mercury sources. Therefore, the low mercury to TSS ratios for the upper Sacramento River watershed may indicate, unless site-specific hot spots are found, that very little total mercury could be removed by means other than erosion control. This has important implications for the implementation plans for total mercury reduction described in Chapter 8 in this TMDL report and Chapter 4 in the Proposed Basin Plan Amendment draft staff report.

Table 7.17: Suspended Sediment to Mercury Ratios for Delta Inputs and Exports (a)

	# of TotHg/TSS Paired Samples	Method A. TotHg Load ÷ TSS Load		Method B. Linear Regression Slope for Paired TotHg/TSS (b)	Method C. Median of TotHg/TSS Paired Sample Results
		WY2000-2003	WY1984-2003		
DELTA INPUTS					
Bear/Mosher Creeks	5	0.12		0.07	0.24
Calaveras River	4	0.25		0.17	0.41
French Camp Slough (c)	5	0.69		0.62 (0.32)	0.20
Marsh Creek	7	0.47		0.12	0.19
Mokelumne-Cosumnes Rivers	21	0.37		0.35	0.41
Morrison Creek (d)	44	0.24		0.16	0.24
Prospect Slough (Yolo Bypass)	24	0.18	0.16	0.16	0.19
Sacramento River (Freeport)	150	0.22	0.21	0.17	0.23
San Joaquin River	30	0.13		0.13	0.14
Ulatis Creek	6	0.13		0.11	0.19
Urban Runoff (e)	128 (123)	0.31		0.18 (0.22)	0.35
DELTA EXPORTS					
Outflows to San Francisco Bay (X2)	21	0.18		0.30	0.28
State Water Project	19	0.25		0.17	0.29
Delta Mendota Canal	21	0.15		0.16	0.18
Dredging (f)	*8 projects*	0.19		- - -	04 to 0.44
TRIBUTARIES TO THE SACRAMENTO BASIN [Sacramento River + Yolo Bypass]					
American River	117	0.46	0.27	0.20	0.41
Cache Creek Settling Basin	22	0.42	0.46	0.47	0.36
Colusa Basin Drain	56	0.09	0.09	0.09	0.07
Feather River	61	0.29	0.30	0.26	0.32
Natomas East Main Drain (Arcade Ck.)	30	0.65		0.22	0.32
Putah Creek	28	1.25	0.64	0.26	0.31
Sacramento River above Colusa	50	0.10	0.10	0.12	0.11
Sutter Bypass (Sacramento Slough)	52	0.14		0.13	0.13

(a) The preferred method for each monitoring location is highlighted in gray. If total mercury concentrations and TSS concentrations both correlated well with daily flow at a given monitoring location, Method A was the preferred method for estimating suspended sediment mercury concentrations. If the available concentration data for a location were too variable and/or sparse to reliably estimate annual average suspended sediment concentrations, none of the values were highlighted. The WY1984-2003 period was evaluated only for Sacramento Basin (Sacramento River and Yolo Bypass) tributaries.

(b) Regressions between total mercury and TSS concentrations are illustrated in Appendix J.

(c) Alternate value noted in parentheses for French Camp Slough does not include one unusually high total mercury result (Appendix J).

(d) Appendix J provides the regressions for each Morrison Creek sampling location. The values noted in this table were generated from the compilation of data from all the sites.

(e) Urban runoff samples were collected at eleven locations. Methods B and C were performed between the urban runoff total mercury and TSS concentration data with and without five dramatically different sample TotHg:TSS ratios observed for Strong Ranch Slough (Appendix J).

(f) Sediment mercury concentrations in dredged material varied substantially across the Delta. The range of project-specific average concentrations was 0.02 to 0.77 mg/kg. The volume-weighted average mercury concentration of all the dredged material was approximately 0.19 mg/kg.

7.4.2 Compliance with the USEPA's CTR

The USEPA's California Toxic Rule mercury objective is 0.05 µg/L (50 ng/l) total recoverable mercury for freshwater sources of drinking water. The CTR criterion was developed to protect humans from exposure to mercury in drinking water and in contaminated fish. It is enforceable for all waters with a municipal and domestic water supply or aquatic beneficial use designation. This includes all subareas of the Delta. The CTR does not specify duration or frequency. As noted in Chapter 2, the Central Valley Water Board has previously employed a 30-day averaging interval with an allowable exceedance frequency of once every three years for protection of human health.

Samples for total mercury analysis were not collected at a frequency to support 30-day averaging. Data therefore do not exist to show whether the CTR has actually been exceeded. To evaluate compliance with the CTR, regression analyses of flow and concentration were used to estimate 30-day running averages. As described in Sections 7.1.1.1 through 7.1.1.3, total mercury concentrations measured in instantaneous grab samples at Delta and Sacramento Basin tributary locations near flow gages were regressed against daily flow to determine if total mercury concentrations for days with no concentration data could be predicted. Figures 7.6 and 7.7 illustrate the regression-based 30-day running averages for locations with statistically significant ($P<0.01$) TotHg/flow correlations. Appendix J provides the TotHg/flow regressions upon which the 30-day averages are based. Table 7.18 provides a summary of the CTR compliance evaluation.

A waterway location was considered to be in compliance if its regression-based 30-day average total mercury exceeded 50 ng/l no more than once in any three-year period. Some locations had total mercury/flow regressions that were not statistically significant; also, some locations with concentration data were not near a flow gage. Such locations on larger waterways (e.g., Mokelumne River and San Joaquin River) were considered likely to be in compliance if none of the grab samples had mercury concentrations that exceeded 50 ng/l. Locations on small tributaries that typically experience short-duration, storm-related high flow events (e.g., French Camp Slough and Ulatis Creek) were considered likely to be in compliance if none of the water samples had mercury concentrations exceeding 50 ng/l, or if the exceedances occurred only during peak storm flows.

The evaluation of regression-based 30-day running average total mercury concentrations and available grab sample total mercury results indicates that all sampled locations within the Delta – except possibly Prospect Slough and Marsh Creek – are in compliance with the CTR criterion for total mercury. Although none of the grab samples collected from Marsh Creek near Highway 4 exceeded 50 ng/l total mercury, the regression-based 30-day running averages indicated that the CTR criterion may have been exceeded during one period. However, only about three years of flow data were available for the Marsh Creek location; therefore, compliance with the CTR criterion cannot be adequately determined with available data. Marsh Creek is already identified on the 303(d) List as impaired by mercury. The future mercury TMDL monitoring program for Marsh Creek will conduct another evaluation of CTR compliance as more data become available.

Evaluation of Yolo Bypass compliance with the CTR is complicated by the variety of watersheds that contribute water to it during varying hydrologic regimes. During low flow conditions, the Yolo Bypass receives flows from coastal mountain watersheds, particularly Cache Creek and Putah Creek, and other agricultural and native areas that drain directly to the bypass (Figure 7.1). During high flow conditions

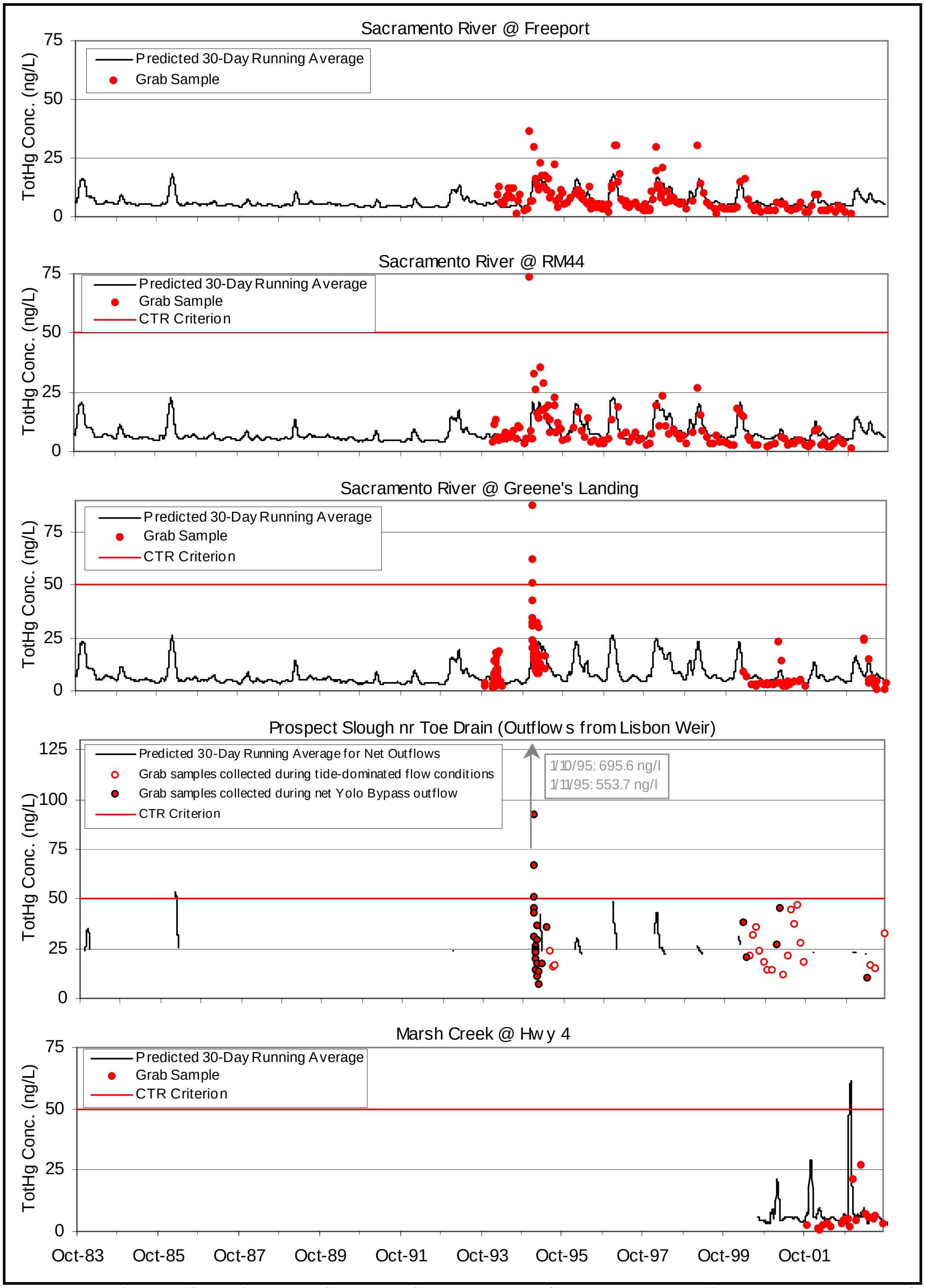

Figure 7.6: Grab Sample and Regression-Based 30-Day Running Average Total Mercury Concentrations for Delta Locations with Statistically Significant (P<0.05) Aqueous TotHg/Flow Correlations

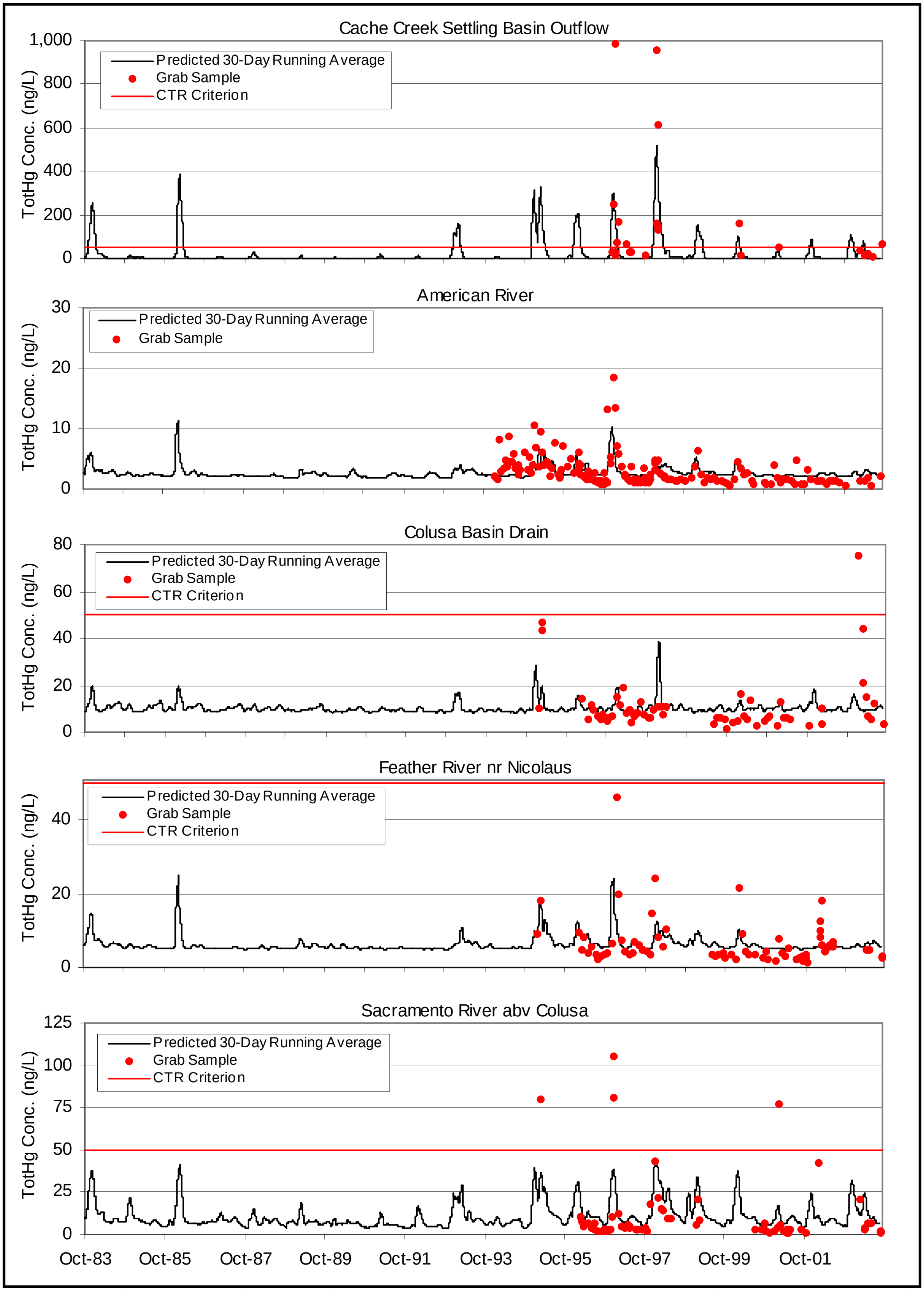

Figure 7.7: Grab Sample and Regression-Based 30-Day Running Average Total Mercury Concentrations for Sacramento Basin Tributary Locations with Statistically Significant (P<0.05) Aqueous TotHg/Flow Correlations

Table 7.18: Evaluation of CTR Compliance at Delta and Sacramento Basin Tributary Locations

Site	Is TotHg/Flow Regression Significant? (a)	Does Predicted 30-Day Average TotHg Ever Exceed CTR's 50 ng/l? (a)	# of Grab Samples > 50 ng/l	Is the Site in Compliance with CTR?
DELTA LOCATIONS				
Bear/Mosher Creeks (b)	- - -	- - -	0	Likely Yes
Calaveras River @ RR u/s West Lane (b)	- - -	- - -	0	Likely Yes
Delta Mendota Canal	No	- - -	0	Likely Yes
French Camp Slough near Airport Way	- - -	- - -	1	Likely Yes
Marsh Creek @ Hwy 4	Yes	Once in 3 year record.	0	***Possibly Not***
Mokelumne River @ I-5	No	- - -	0	Likely Yes
Morrison Creek (c)	- - -	- - -	0	Likely Yes
Outflow to San Francisco Bay	No	- - -	0	Likely Yes
Prospect Slough (Yolo Bypass) (d)	Yes	Once (d).	5	***Possibly Not***
Sacramento River @ Freeport (e)	Yes	No.	0	Yes
Sacramento River @ Greene's Landing (e)	Yes	No.	4	Yes
Sacramento River @ RM44 (e)	Yes	No.	1	Yes
San Joaquin River @ Vernalis	No	- - -	0	Likely Yes
State Water Project	No	- - -	0	Likely Yes
Ulatis Creek near Main Prairie Rd	- - -	- - -	2	Likely Yes
SACRAMENTO BASIN TRIBUTARIES (f)				
American River @ Discovery Park	Yes	No.	0	Yes
Cache Creek d/s Settling Basin	Yes	In 11 of 20 years.	15	***No***
Colusa Basin Drain	Yes	No.	2	Yes
Feather River near Nicolaus	Yes	No.	0	Yes
Natomas East Main Drain (g)	- - -	- - -	1	Unknown
Putah Creek @ Mace Blvd.	No	- - -	4	***Possibly Not***
Sacramento River above Colusa	Yes	No.	4	Yes
Sacramento Slough near Karnak (h)	No	- - -	0	Likely Yes

(a) Flow gage data were not available for most of the small tributary outflows to the Delta. All of the regressions for sampling locations near a flow gage were based on 20-year flow datasets except for Marsh Creek, for which only a 3-year dataset was available. Regressions were considered statistically significant for R^2 values with $P < 0.05$. Appendix J provides the regression plots.

(b) Only wet weather events were sampled on the Calaveras River and Bear and Mosher Creeks in Stockton. The one wet weather Mosher Creek sample result was combined with the Bear Creek dataset to evaluate compliance for both creeks.

(c) Concentration data collected at multiple sites on lower Morrison Creek were compiled to evaluate compliance.

(d) Sampling took place at Prospect Slough (export location of the Yolo Bypass) both when there were net outflows from tributaries to the Yolo Bypass and when there was no net outflow (i.e., the slough's water was dominated by tidal waters from the south). The regression analysis focuses only on the conditions when there was net outflow from the Yolo Bypass. Available flow information (Appendix E) indicates that during many years, the Yolo Bypass does not have a net outflow that lasts for 30 days or more.

(e) The Sacramento River sampling locations at Freeport and River Mile 44 (RM44) are upstream and downstream, respectively, of the outfall for the Sacramento Regional County Sanitation District's Sacramento River Wastewater Treatment Plant. Greene's Landing is about nine miles downstream of the RM44 sampling location. Concentration data collected at all three sites were regressed against the flow data recorded at the Freeport gage, as no other gages are operational in this river reach. Appendix M provides the total mercury concentration data available for all three Sacramento River locations.

(f) Flows from the listed tributary watersheds may be diverted to the Yolo Bypass during high flow conditions via Knights Landing Ridge Cut, Fremont Weir and Sacramento Weir. The Coon Creek/Cross Canal watershed also contributes to the Sacramento River downstream of the Feather River but no aqueous total mercury data are available for its discharges.

(g) No concentration or flow data gage data were available for Natomas East Main Drain outflows. The SRWP, USGS and City of Roseville collected total mercury concentration data on Arcade Creek near Norwood and Del Paso Heights and Dry Creek. It was assumed that this dataset characterizes NEMD outflows.

(h) Sacramento Slough near Karnak is the low flow channel for Sutter Bypass.

on the Sacramento River, excess flows from the upper Sacramento River, Sutter Bypass, Feather River, Colusa Basin, and American River watersheds may be routed down the Yolo Bypass at Fremont Weir, Sacramento Bypass and Knights Landing Ridge Cut. In a typical storm event, flows from the Cache Creek Settling Basin (northwest and outside of the legal Delta boundary) and other local sources reach the Yolo Bypass first, to be followed by lower concentration inputs from the Colusa Basin, Sacramento River and Feather River.

As indicated in Figure 7.7 and described in detail in Appendix E (Section E.2.2 and Figure E.2), the Yolo Bypass may not experience 30 days of continuous net outflow from Lisbon Weir upstream of Prospect Slough during dry years. In addition, storm data collected in 1995 indicate that total mercury concentrations in Prospect Slough (the primary outflow from the Bypass to the Delta) peak for a very short time. To evaluate conditions within the Bypass, the total mercury levels in tributary inputs to the Bypass were evaluated (Figure 7.7). The regression-based 30-day averages of predicted total mercury concentrations in the Sacramento River upstream of Colusa and the Feather River indicate that their flows are in compliance with the CTR criterion. However, the regression-based 30-day running average total mercury concentrations in Cache Creek Settling Basin outflows indicate that Cache Creek flows into the Yolo Bypass are not in compliance with the CTR criterion. The TotHg/flow regression for Putah Creek was not statistically significant; therefore, compliance with the CTR criterion cannot be adequately determined with available data. However, four grab samples collected from two separate storm events (one in March 1995, the other in March 2004) on Putah Creek had mercury levels between 52 and 485 ng/l, indicating that inputs from Putah Creek to the Yolo Bypass also may not be in compliance with the CTR criterion. This implies that when the Bypass is dominated by flows from Cache and Putah Creeks, it may not be in compliance with the CTR criterion. Therefore, Yolo Bypass areas downstream of the Cache Creek Settling Basin and Putah Creek outflows probably do not meet the CTR criterion.

The Basin Plan Amendment for control of mercury in Cache Creek was adopted by the Central Valley Water Board in October 2005. As outlined in the Basin Plan Amendment report (Cooke & Morris, 2005), implementation actions would enable CTR compliance in outflows from Cache Creek. Continued monitoring of Putah Creek outflows to the Yolo Bypass as part of implementation activities for the Delta mercury TMDL could enable better evaluation of CTR compliance. In order to meet the mercury loading allocation proposed for the Central Valley by San Francisco Water Board staff, the total mercury reduction strategy described in Chapter 8 assigns a 37% load reduction to mercury exports from the Feather River, American River and Putah Creek. In addition, Putah Creek is already identified on the 303(d) List as impaired by mercury. If future monitoring indicates that Putah Creek and Cache Creek Settling Basin outflows to the Yolo Bypass do not comply with the CTR even after proposed total mercury reductions described are achieved, and other reductions designed to accomplish safe fish tissue methylmercury levels in Cache Creek and Putah Creek are achieved, additional reductions will be required.

Key Points

- The primary sources of total mercury in the Delta include tributary inflows from upstream watersheds, atmospheric deposition, urban runoff, and municipal and industrial wastewater. Losses include flow to San Francisco Bay, water exports to southern California, removal of dredged sediments and evasion.
- More than 96% of identified total mercury loading to the Delta comes from tributary inputs; within-Delta sources are a very small component of overall loading.
- The Sacramento Basin (Sacramento River + Yolo Bypass) contributed approximately 80% or more of total mercury fluxing through the Delta, most of which was transported during winter storms.
- Outflow to San Francisco Bay accounted for approximately 50% or more of total mercury exported from the Delta.
- The Cache Creek, Feather River, American River and Putah Creek watersheds in the Sacramento Basin had both relatively large mercury loadings and high mercury to TSS ratios, making them attractive candidates for remediation.

8 METHYLMERCURY ALLOCATIONS, TOTAL MERCURY LIMITS & MARGIN OF SAFETY

This chapter presents recommended methylmercury allocations and total mercury limits for methyl and total mercury sources to the Delta. Reductions in aqueous methylmercury are required to reduce methylmercury concentrations in fish. Reductions in total mercury loads are needed to enable aqueous and fish methylmercury reductions and to comply with the USEPA's CTR criterion for human protection and San Francisco Bay Mercury TMDL total mercury allocation for the Central Valley. Section 8.1 describes the proposed load and wasteload allocations for within-Delta and tributary inputs of methylmercury by source category. Section 8.2 describes the proposed total mercury limits and reductions. Sections 8.3 and 8.4 describe the associated margin of safety and inter-annual and seasonal variability.

The methylmercury allocations and total mercury limits described in this chapter reflect the preferred implementation alternative described in Chapter 4 of the Proposed Basin Plan Amendment draft staff report and are designed to address the beneficial use impairment in all subareas of the Delta and San Francisco Bay. However, as described in the draft Basin Plan Amendment report, a number of alternatives are possible. The Central Valley Water Board will consider a variety of allocation strategies and implementation alternatives as part of the basin plan amendment process.

8.1 Methylmercury Load Allocations

A water body's loading capacity (assimilative capacity) represents the maximum rate of loading of a pollutant that the water body can assimilate without violating water quality standards. A TMDL typically represents the sum of all individual allocations of the water body's assimilative capacity and must be less than or equal to the assimilative capacity. Allocations are divided among "wasteload allocations" for point sources and "load allocations" for nonpoint sources. The TMDL is the sum of these components:

Equation 8.1:

$$\text{TMDL} = \text{Background} + \text{Wasteload Allocations} + \text{Load Allocations}$$

A TMDL need not be stated as a daily load (Code of Federal Regulations, Title 40, §130.2[i]). Other measures are allowed if appropriate. The methylmercury allocation scheme proposed below is expressed in terms of average annual concentrations and loads because the adverse effects of mercury occur through long-term bioaccumulation. The allocations are intended to represent annual averages and account for both seasonal and long-term variability.

Methylmercury allocations were made in terms of the existing assimilative capacity of each of the different Delta subareas. A methylmercury TMDL must be developed for each Delta subarea because the sources and percent reductions needed to meet the proposed implementation goal are different in each subarea. The linkage analysis (Chapter 5) described the calculation of an implementation goal for aqueous methylmercury that is linked to the fish tissue methylmercury targets. The recommended implementation goal is an annual average concentration of 0.06 ng/l methylmercury in unfiltered water. This goal describes the assimilative capacity of Delta waters in terms of concentration (Section 5.2). Central Valley Water Board staff anticipates that as the average concentration of methylmercury in each

Delta subarea decreases to the safe aqueous goal, then the targets for fish tissue will be attained. To determine necessary reductions, the existing average aqueous methylmercury levels in each Delta subarea were compared to the methylmercury goal (Table 8.1).

The amount of reduction needed in each subarea is expressed as a percent of the existing concentration. As noted in the linkage analysis, the aqueous methylmercury goal was developed using water data for March to October 2000 because this was the only period for which there was overlap between water data and the lifespan of the fish. Table 8.1 compares the proposed goal to average methylmercury concentrations for March to October 2000 (Scenario A) and for March 2000 to April 2004 (Scenario B). Scenario B is based on a much larger dataset and includes values for all seasons. However, the percent reductions are similar for both scenarios and range from 0 to 80% for the different subareas. Therefore, staff recommends the use of the proposed reductions listed in Scenario B for the calculation of assimilative capacity.

The assimilative capacity of each subarea (Table 8.2) was determined using the proposed reductions listed in Scenario B in Table 8.1 (except for the Central Delta subarea, as discussed in the next paragraph), the sum of existing annual methylmercury inputs from identified sources (Table 8.3,[46] at the end of this section) and the following equation:

Equation 8.2: (using the Sacramento subarea as an example)

$$\text{Assimilative Capacity (g/yr)} = \text{Existing MeHg Inputs (g/yr)} - \left[\text{\% Reduction Needed to Meet Proposed Goal} \times \text{Existing MeHg Inputs (g/yr)}\right]$$

$$= 2{,}418 \text{ g/yr} - (44\% * 2{,}418 \text{ g/yr})$$
$$= 1{,}354 \text{ g/yr}$$

Scenarios A and B indicate no reduction is needed for ambient methylmercury in the Central Delta subarea to meet the proposed implementation goal. Because Central Delta water quality is dominated by inflows from upstream Delta subareas that require reductions ranging from 44 to 80%, Central Delta fish tissue and aqueous methylmercury levels are expected to decrease when actions are implemented to reduce up-basin aqueous methylmercury levels. Therefore, staff recommends that no reduction be required for point and nonpoint source methylmercury discharges within the Central Delta subarea. However, staff recommends a policy of no net increase in ambient methylmercury concentrations in the Central Delta subarea to ensure that fish methylmercury concentrations do not increase. This can be achieved by setting the acceptable methylmercury concentrations in Table 8.3 for Central Delta sources at their existing levels. In addition, staff recommends that source discharges with average methylmercury concentrations above the proposed aqueous methylmercury goal of 0.06 ng/l have load allocations set at their existing levels. No load allocations are needed for sources with existing discharge methylmercury concentrations at or below the implementation goal because they act as dilution. However, the loads for such discharges are listed in brackets in Table 8.3 to enable the calculation of the percent allocations required for other sources to meet the implementation goal in ambient waters given current conditions.

[46] "Existing annual MeHg loads" in Table 8.3 represent the loads estimated for WY2000-2003, a relatively dry period. Actual loads from MS4 discharges and nonpoint sources are expected to fluctuate with water volume and other environmental factors. Load estimates will be re-evaluated in subsequent phases of the TMDL as more data become available.

Table 8.1: Aqueous Methylmercury Reductions Needed to Meet the Proposed Methylmercury Goal of 0.06 ng/l. (a)

	Delta Subarea						
	Central Delta	Marsh Creek	Mokelumne River	Sacramento River	San Joaquin River	West Delta	Yolo Bypass
A. Scenario Based on March to October 2000 Aqueous MeHg Data (b)							
Average Aqueous MeHg Concentration (ng/l)	0.055	0.224	0.140	0.120	0.147	0.087	0.305
Percent Reduction Needed to Meet the Proposed MeHg Goal	0%	73%	57%	50%	59%	31%	80%
B. Scenario Based on March 2000 to April 2004 Aqueous MeHg Data (b)							
Average Annual Aqueous MeHg Concentration (ng/l)	0.060	0.224	0.166	0.108	0.160	0.083	0.273
Percent Reduction Needed to Meet the Proposed MeHg Goal	0%	73%	64%	44%	63%	28%	78%

(a) The amount of reduction needed in each subarea is expressed as a percent of the existing methylmercury concentration. For example, the percent reduction needed for the Marsh Creek subarea Scenario A is calculated by: (0.244 - 0.06) / 0.244 = 73%. The average March to October 2000 methylmercury concentration for the Central Delta is below the proposed implementation goal of 0.06 ng/l. As a result, Scenario A calculations for the Central Delta result in negative numbers: A(1): (0.055 - 0.06)/0.055 = -9%. No reduction is needed under Scenario A or B for Central Delta ambient methylmercury.

(b) Average concentrations are based on unfiltered MeHg concentration data collected at the following locations: Delta Mendota Canal and State Water Project (Central Delta); Marsh Creek at Highway 4; Mokelumne River near I-5; Sacramento River at Freeport, RM44 and Greene's Landing; San Joaquin River near Vernalis; outflow to San Francisco Bay measured at X2, usually near Mallard Island (West Delta); and Prospect Slough near Toe Drain (Yolo Bypass). The values for the Central Delta, Mokelumne River, Sacramento River, San Joaquin and West Delta subareas are described in Section 5.1 and Table 5.1 in Chapter 5 and are based on monthly average concentrations so that the average concentrations for each study period are not influenced by the unequal number of samples collected in each month. The Yolo Bypass average concentrations also are based on monthly average concentrations. The sampling frequency on Marsh Creek was inadequate to develop averages for each study period, much less to pool data by month; therefore, the average of all available concentration data was used in both scenarios. The Yolo Bypass and Marsh Creek data are described in Chapter 6, Section 6.2.1 and Table 6.3. It was assumed that the sampling locations are representative of the subareas in which they occur.

Table 8.2: Assimilative Capacity Calculations for Each Delta Subarea.

Delta Subarea	**Existing Average Annual MeHg Conc.** (a) (ng/l)	**% Reduction Needed to Achieve Proposed Goal of 0.06 ng/l** (a)	**Existing Annual MeHg Load from Identified Sources** (b) (g/yr)	**Assimilative Capacity** (g/yr)
Central Delta	0.060	0%	524	524
Marsh Creek	0.224	78%	6.6	1.4
Mokelumne River	0.166	69%	123	38
Sacramento River	0.108	49%	2,414	1,221
San Joaquin River	0.160	68%	478	155
West Delta	0.083	0%	320	320
Yolo Bypass [North & South]	0.273	83%	1,068	181

(a) No percent reductions are proposed for the Central and West Delta subareas because their fish tissue and aqueous methylmercury levels either currently achieve or are expected to achieve safe levels when actions are implemented to reduce up-basin aqueous methylmercury levels. Proposed reductions for other subareas are from Table 8.1 Scenario B.

(b) "Existing annual MeHg loads" represent the sum of all identified inputs to each subarea (Chapter 6 and Table 8.3).

The subareas on the eastern boundary of the Delta require substantial reductions in fish and aqueous methylmercury levels. In contrast, ambient methylmercury concentrations in the West Delta subarea approach the proposed aqueous methylmercury goal of 0.06 ng/l, resulting in the need for only modest reductions in methylmercury sources. The primary within-subarea source of methylmercury in the West

Delta subarea is sediment flux from open channel habitats (Table 8.3), for which there is no responsible party yet identified. In addition, it is expected that, should the proposed reductions take place in sources to the upstream Delta subareas, the proposed aqueous goal will be met in the West Delta subarea. (For example, the Sacramento subarea – the largest source of water to the West Delta subarea – requires a source reduction of 44%.) Therefore, staff recommends that no reduction be required for point and nonpoint source methylmercury discharges within the West Delta subarea. However, staff recommends a policy of no net increase in ambient methylmercury concentrations in the West Delta subarea to ensure that fish methylmercury concentrations do not increase. This can be achieved by using the same allocation strategy described in the previous paragraph for Central Delta methylmercury sources.

Staff recommends that atmospheric deposition and sediment flux from open water habitats be considered background sources in all Delta subareas and assigned no net increase in methylmercury concentration or loading. Discharges from urban areas outside of MS4 service areas comprise less than 4% of all urban acreage and associated urban methylmercury loading to the Delta, and a fraction of a percent of total mercury loading to the Delta; as a result, they will be assigned allocations in 2014 and are considered capped for calculation of Delta-wide allocations.[47] In addition, staff recommends that source discharges with average methylmercury concentrations below the proposed aqueous methylmercury goal of 0.06 ng/l be considered dilution and assigned no net increase in methylmercury concentration. The acceptable methylmercury concentrations in Table 8.3 for such sources were set at their existing levels. No load allocations are needed for sources with existing discharge methylmercury concentrations at or below the implementation goal because they act as dilution. However, the loads for such discharges are listed in brackets in Table 8.3 to enable the calculation of percent allocations required for other sources to meet the implementation goal in ambient waters given current conditions.

The following equation was used to determine the percent allocations needed for the remaining sources to achieve the assimilative capacity in each Delta subarea:

Equation 8.3: (using the Sacramento subarea as an example)

Percent Allocations for Other Sources Developed Using Average Annual Methylmercury Loads:

$$= \frac{\text{Assim. Cap.} - (\text{Atm. Dep.} + \text{Open Water Sed. Flux} + \text{Nonpoint Urban} + \text{Sources w/ Ave. MeHg Conc.} \leq 0.06\text{ ng/l})}{(\text{Sum of All Sources}) - (\text{Atm. Dep.} + \text{Open Water Sed. Flux} + \text{Nonpoint Urban} + \text{Sources w/ Ave. MeHg Conc.} \leq 0.06\text{ ng/l})}$$

$$= \frac{1{,}354\text{ g/yr} - (1.5\text{ g/yr} + 118\text{ g/yr} + 0.64\text{ g/yr} + 0.40\text{ g/yr})}{2{,}418\text{ g/yr} - (1.5\text{ g/yr} + 118\text{ g/yr} + 0.64\text{ g/yr} + 0.40\text{ g/yr})}$$ *[West Sacramento WWTP average discharge is ≤0.06 ng/l.]*

= 53.7%

The percent allocations were applied to every point and nonpoint source discharge load and concentration – except those with concentrations capped at existing levels – within each subarea to calculate acceptable methylmercury concentrations and loads (Table 8.3) using the following equations:

[47] As described in Chapter 4 of the Proposed Basin Plan Amendment Draft Staff Report, if such urban communities expand significantly, or are found to be significant contributors of methylmercury or other pollutants, they will be designated Phase II MS4 dischargers and required to develop and implement mercury control plans like those proposed for existing Phase II dischargers.

Equation 8.4a: (using SRCSD SRWWTP effluent concentration as an example)

$$\text{Acceptable MeHg Concentration} = \text{\% Allocation} * \text{Average SRCSD SRWWTP Effluent Conc.}$$
$$= 53.7\% * 0.727 \text{ ng/l}$$
$$= 0.390 \text{ ng/l}$$

Equation 8.4b: (using SRCSD SRWWTP effluent load as an example)

$$\text{Acceptable MeHg Load} = \text{\% Allocation} * \text{Annual SRCSD SRWWTP Load}$$
$$= 53.7\% * 157 \text{ g/yr}$$
$$= 84 \text{ g/yr}$$

Sometimes the use of Equation 8.4a resulted in a value less than 0.06 ng/l. Staff recommends that no source discharge be required to reduce its discharge methylmercury concentrations to less than 0.06 ng/l during the first phase of the implementation program. Therefore, if use of Equation 8.4a resulted in a value less than 0.06 ng/l for a particular source discharge, the acceptable methylmercury concentration (Table 8.3) was set at 0.06 ng/l and the allocation percent and equivalent load were calculated by the following equations:

Equation 8.5a: (using the City of Tracy WWTP in the San Joaquin subarea as an example)

$$\text{\% Allocation} = \text{Proposed Implementation Goal} \div \text{Existing Average MeHg Conc.}$$
$$= 0.06 \text{ ng/l} \div 0.146 \text{ ng/l}$$
$$= 41.1\%$$

Equation 8.5b:

$$\text{Equivalent MeHg Load} = \text{\% Allocation} * \text{Existing Annual MeHg Load}$$
$$= 41.1\% * 1.9 \text{ g/yr}$$
$$= 0.8 \text{ g/yr}$$

No load allocations are needed for sources with allocated discharge methylmercury concentrations of 0.06 ng/l or less because they will act as dilution if their allocations are maintained. However, the loads for such discharges are listed in brackets in Table 8.3 and included in Equation 8.3 (in the "Sources w/ Ave. MeHg Conc. ≤0.06 ng/l" component) to enable the calculation of percent allocations required for other sources to meet the implementation goal in ambient waters. The ultimate purpose of this iterative set of calculations is to ensure that the sum of all methylmercury inputs to each Delta subarea does not exceed the assimilative capacity so that the proposed implementation goal for ambient water can be achieved in each subarea.

Limited methylmercury concentration data exist for specific NPDES-permitted MS4s and nonpoint sources (e.g., agricultural and sediment flux) in each Delta subarea. Allocations for MS4s and nonpoint sources will be updated as additional results become available.

Tributary inputs account for about half of the methylmercury loading to the Delta (Figure 6.11). Methylmercury load reductions from tributary inputs will be needed to achieve the numeric targets in the Delta. Substantial aqueous methylmercury data are available for some of these inputs – enough to assign load allocations for the tributary inputs. The tributary allocations are treated as load allocations because there is insufficient information to assign load allocations to specific nonpoint sources (e.g., wetland and agricultural inputs) within the tributary watersheds at this time. Several of the tributary watersheds contain 303(d) listed waterways; future TMDLs are planned for these watersheds. Site-specific point and nonpoint source load reductions will be assigned as basin plan amendments are developed for each of these. However, there are several tributary watersheds that discharge to Delta subareas that require substantial mercury reductions (e.g., Mokelumne River and Ulatis Creek), for which no TMDLs are planned because none of waterways in these watersheds are currently 303(d) listed. Staff recommends that these watersheds be evaluated as part of Phase II of the proposed implementation plan (see Chapter 4 in the Proposed Basin Plan Amendment draft staff report).

There are several NPDES-permitted facilities and MS4s just outside the legal Delta boundary in the Delta's tributary watersheds. There is a need for a methylmercury control program that can consistently address permittees within and adjacent to the Delta. For this reason, staff evaluated upstream permittees. The alternatives analysis in Chapter 4 of the Proposed Basin Plan Amendment draft staff report identified a scope of 30 miles upstream of the Delta as the preferred option because: (a) 30 miles represents approximately 1-day travel time by water (sources within this distance may directly contribute to the Delta); and (b) it encompasses the MS4 service areas that have discharge points adjacent to or within the Delta. Appendix G provides potential methylmercury allocations for point sources (NPDES permitted facilities and MS4s) within 30 miles of the legal Delta boundary organized by tributary. The allocations are based on the percent reductions required for each tributary input to achieve the aqueous methylmercury implementation goal in each Delta subarea. Appendix G also provides a list of the point sources upstream of the 30-mile radius and downstream of major dams. The Central Valley Water Board will evaluate several alternatives to ultimately determine the scope of the Delta methylmercury control program.

As described in Chapter 4 of the Proposed Basin Plan Amendment draft staff report, staff recommends that responsibility parties for point and nonpoint methylmercury discharges conduct collaborative source characterization and control studies during the next six or so years. To the extent the efforts to develop methylmercury controls are effective, and/or further scientific information has been collected, the Central Valley Water Board may consider amendments to the Basin Plan to update the methylmercury allocations and implementation plan after the studies are completed.

About thirty percent of the methylmercury in the Delta is produced locally in sediment (Figure 6.11). Methylmercury production is a positive linear function of the inorganic mercury content of sediment (Chapter 3). This TMDL requires a 110-kg/yr reduction in total mercury from upstream watersheds with mercury sediment concentrations greater than 0.2 mg/kg and large mercury loads (next section). This represents about a 26% decrease in the 20-year average annual loading from the Sacramento Basin (Table 8.4) and should eventually result in a similar proportional decrease in sediment mercury concentrations. Inorganic mercury load reductions elsewhere have resulted in decreases in fish tissue methylmercury concentrations (Table 3.1). It is expected that similar reductions in fish tissue concentration also will occur in the Delta once the mercury content of its sediment decreases.

Proposed total mercury load reductions are described in Section 8.2, after Tables 8a through 8g.

Table 8.3a: Allocations for Methylmercury Sources to the Central Delta Subarea (a)

MeHg Sources	Tributary or Permittee	Permit #	Existing Average Annual MeHg Conc. (ng/l)	Existing Average Annual MeHg Load (g/yr)	Percent Allocation	Acceptable MeHg Conc. (g/yr)	Acceptable MeHg Load (g/yr)
BACKGROUND							
Atmospheric Deposition			*Not applicable.*	3.2	100%	*Not applicable.*	3.2
Sediment Flux	Open Water Habitats		*Not applicable.*	301	100%	*Not applicable.*	301
LOAD ALLOCATIONS							
Agricultural Drainage			0.352	37	100%	0.352	37
Sediment Flux	Wetland Habitats		*Not applicable.*	135	100%	*Not applicable.*	135
Tributary Inputs	Calaveras River		0.144	25	100%	0.144	25
	Bear/Mosher Creeks		0.310	11	100%	0.310	11
Urban (nps) (b)			0.241	0.13	100%	0.241	0.13
WASTELOAD ALLOCATIONS (c)							
MS4	City of Lodi	CAS000004	0.241	0.053	100%	0.241	0.053
	County of Contra Costa	CAS083313	0.241	0.75	100%	0.241	0.75
	County of San Joaquin	CAS000004	0.241	0.57	100%	0.241	0.57
	Port of Stockton MS4	CAS084077	0.241	0.39	100%	0.241	0.39
	Stockton Area MS4	CAS083470	0.241	3.6	100%	0.241	3.6
Facilities	Discovery Bay WWTP	CA0078590	0.199	0.42	100%	0.199	0.42
	City of Lodi White Slough WWTP	CA0079243	0.131	0.72	100%	0.131	0.72
	San Joaquin Co DPW CSA 31-Flag City WWTP	CA0082848	0.085	0.007	100%	0.085	0.007
CENTRAL DELTA SUBAREA TOTAL:			**0.060**	**519**	**100%**	**0.060**	**519**

(a) Existing concentrations were rounded to three decimal places, and existing loads were rounded to two significant digits, before calculating acceptable concentrations and loads. Acceptable concentrations are provided to three decimal places for ease of verifying calculations. However, staff recommends that they be rounded to two decimal places to evaluate compliance.

(b) Urban areas not encompassed by a MS4 service area were grouped into the "nonpoint source" (nps) category, which is considered a load allocation rather than a wasteload allocation.

(c) Permittees with NPDES No. CAS000004 are covered under the General Permit for the discharge of storm water from small MS4s (WQ Order No. 2003-0005-DWQ) adopted by the State Board to provide permit coverage for smaller municipalities (serving less than 100,000 people).

Table 8.3b: Allocations for Methylmercury Sources to the Marsh Creek Subarea (a)

MeHg Sources	Tributary or Permittee	Permit #	Existing Average Annual MeHg Conc. (ng/l)	Existing Average Annual MeHg Load (g/yr)	Percent Allocation	Acceptable MeHg Conc. (g/yr)	Acceptable MeHg Load (g/yr) (b)
			BACKGROUND				
Atmospheric Deposition			*Not applicable.*	0.00049	100%	*Not applicable.*	0.00049
Sediment Flux	Open Water Habitats		*Not applicable.*	0.033	100%	*Not applicable.*	0.033
			LOAD ALLOCATIONS				
Agricultural Drainage			0.352	2.2	25.5%	0.090	0.56
Sediment Flux	Wetland Habitats		*Not applicable.*	0.40	25.5%	*Not applicable.*	0.10
Tributary Inputs	Marsh Creek		0.255	1.9	25.5%	0.065	0.48
			WASTELOAD ALLOCATIONS				
MS4	County of Contra Costa	CAS083313	0.241	1.2	25.5%	0.061	[0.31]
Facilities	City of Brentwood WWTP	CA0082660	0.020	0.085	100%	0.020	[0.085]
MARSH CREEK SUBAREA TOTAL:			**0.224**	**5.8**	**27%**	**0.060**	**1.6**

(d) Existing concentrations were rounded to three decimal places, and existing loads were rounded to two significant digits, before calculating acceptable concentrations and loads. Acceptable concentrations are provided to three decimal places for ease of verifying calculations. However, staff recommends that they be rounded to two decimal places to evaluate compliance.

(e) No load allocations are needed for sources with existing (e.g., City of Brentwood WWTP) or allocated (e.g., Contra Costa MS4) discharge methylmercury concentrations at or below the implementation goal because the discharges act as dilution. However, the loads for such discharges are listed in brackets ("[ ]") in this table to enable the calculation of the percent allocations required for other sources to ultimately meet the implementation goal in ambient waters given current conditions. "Percent allocations" listed for these sources may be greater than for other sources because staff recommends that sources with existing average concentrations less the implementation goal maintain their existing concentration, and that no source discharge be required to reduce its discharge methylmercury concentrations to less than 0.06 ng/l during the first phase of the implementation program.

Table 8.3c: Allocations for Methylmercury Sources to the Mokelumne/Cosumnes Rivers Subarea (a)

MeHg Sources	Tributary or Permittee	Permit # (a)	Existing Average Annual MeHg Conc. (ng/l)	Existing Average Annual MeHg Load (g/yr)	Percent Allocation	Acceptable MeHg Conc. (g/yr)	Acceptable MeHg Load (g/yr)
			BACKGROUND				
Atmospheric Deposition			*Not applicable.*	0.024	100%	*Not applicable.*	0.024
Sediment Flux	Open Water Habitats		*Not applicable.*	1.1	100%	*Not applicable.*	1.1
			LOAD ALLOCATIONS				
Agricultural Drainage			0.352	1.6	35.4%	0.125	0.57
Sediment Flux	Wetland Habitats		*Not applicable.*	12	35.4%	*Not applicable.*	4.2
Tributary Inputs	Mokelumne River		0.166	108	35.4%	0.059	38
Urban (nps)			0.241	0.018	35.4%	0.085	0.0064
			WASTELOAD ALLOCATIONS				
MS4	County of San Joaquin	CAS000004	0.241	0.051	35.4%	0.085	0.018
MOKELUMNE/COSUMNES RIVERS SUBAREA TOTAL:			**0.166**	**123**	**36%**	**0.060**	**44**

(a) Existing concentrations were rounded to three decimal places, and existing loads were rounded to two significant digits, before calculating acceptable concentrations and loads. Acceptable concentrations are provided to three decimal places for ease of verifying calculations. However, staff recommends that they be rounded to two decimal places to evaluate compliance.

Table 8.3d: Allocations for Methylmercury Sources to the Sacramento River Subarea (a)

MeHg Sources	Tributary or Permittee	Permit #	Existing Average Annual MeHg Conc. (ng/l)	Existing Average Annual MeHg Load (g/yr)	Percent Allocation	Acceptable MeHg Conc. (g/yr)	Acceptable MeHg Load (g/yr) (b)
BACKGROUND							
Atmospheric Deposition			*Not applicable.*	1.5	100%	*Not applicable.*	1.50
Sediment Flux	Open Water Habitats		*Not applicable.*	118	100%	*Not applicable.*	118
LOAD ALLOCATIONS							
Agricultural Drainage			0.352	36	53.7%	0.189	19
Sediment Flux	Wetland Habitats		*Not applicable.*	66	53.7%	*Not applicable.*	35
Tributary Inputs	Sacramento River		0.103	2,026	53.7%	0.055	1,088
	Morrison Creek		0.102	8.1	53.7%	0.055	4.3
Urban (nonpoint source)			0.241	0.64	53.7%	0.129	0.34
WASTELOAD ALLOCATIONS							
MS4	City of West Sacramento	CAS000004	0.241	0.62	53.7%	0.129	0.33
	County of San Joaquin	CAS000004	0.241	0.19	53.7%	0.129	0.10
	County of Solano	CAS000004	0.241	0.074	53.7%	0.129	0.040
	County of Yolo	CAS000004	0.241	0.073	53.7%	0.129	0.039
	Sacramento Area MS4	CAS082597	0.241	3.0	53.7%	0.129	1.6
Facilities	City of Rio Vista WWTP	CA0079588	0.164	0.11	53.7%	0.088	0.06
	City of Rio Vista Trilogy WWTP	CA0083771	tbd	tbd	tbd	tbd	tbd
	Sacramento Regional CSD Walnut Grove WWTP	CA0078794	1.689	0.19	53.7%	0.907	0.10
	Sacramento Regional CSD Combined WWTP (c)	CA0079111	0.241	0.43	53.7%	0.129	0.23
	Sacramento Regional CSD Sacramento River WWTP	CA0077682	0.727	157	53.7%	0.390	84
	City of West Sacramento WWTP	CA0079171	0.051	0.40	100%	0.051	[0.40]
SACRAMENTO RIVER SUBAREA TOTAL:			**0.108**	**2,418**	**56%**	**0.060**	**1,354**

(a) Existing concentrations were rounded to three decimal places, and existing loads were rounded to two significant digits, before calculating acceptable concentrations and loads. Acceptable concentrations are provided to three decimal places for ease of verifying calculations. However, staff recommends that they be rounded to two decimal places to evaluate compliance.

(b) No load allocations are needed for sources with existing average discharge methylmercury concentrations at or below the implementation goal (e.g., City of West Sacramento WWTP) because the discharges act as dilution. However, the loads for such discharges are listed in brackets ("[ ]") in this table to enable the calculation of the percent allocations required for other sources to ultimately meet the implementation goal in ambient waters given current conditions. "Percent allocations" listed for these sources may be greater than for other sources because staff recommends that sources with existing average concentrations less the implementation goal maintain their existing concentration during the first phase of the implementation program.

(c) Because the City of Sacramento Combined Sewer System (CSS) discharges predominantly urban storm runoff with some domestic and industrial wastewater, and no methylmercury data are available for CSS discharges, the wet weather methylmercury concentration (0.24 ng/l) used to calculate storm runoff loads in Section 6.2.5 was used to develop a preliminary load estimate for the CSS. The CSS effluent methylmercury load will be re-calculated using data provided by 13267 monitoring reports once they are submitted.

Table 8.3e: Allocations for Methylmercury Sources to the San Joaquin River Subarea (a)

MeHg Sources	**Tributary or Permittee**	**Permit #**	**Existing Average Annual MeHg Conc.** (ng/l)	**Existing Average Annual MeHg Load** (g/yr)	**Percent Allocation**	**Acceptable MeHg Conc.** (g/yr)	**Acceptable MeHg Load** (g/yr) (b)
BACKGROUND							
Atmospheric Deposition			*Not applicable.*	0.41	100%	*Not applicable.*	0.41
Sediment Flux	Open Water Habitats		*Not applicable.*	20	100%	*Not applicable.*	20
LOAD ALLOCATIONS							
Agricultural Drainage			0.352	23	17.8%	0.063	4.1
Sediment Flux	Wetland Habitats		*Not applicable.*	18	17.8%	*Not applicable.*	3
Tributary Inputs	San Joaquin River		0.160	356	37.5%	0.060	134
	French Camp Slough		0.142	11	42.3%	0.060	4.6
Urban (nps)			0.241	0.0022	24.9%	0.060	[0.00055]
WASTELOAD ALLOCATIONS							
MS4	City of Lathrop	CAS000004	0.241	0.27	24.9%	0.060	[0.07]
	City of Tracy	CAS000004	0.241	1.8	24.9%	0.060	[0.45]
	County of San Joaquin	CAS000004	0.241	2.6	24.9%	0.060	[0.65]
	Port of Stockton MS4	CAS084077	0.241	0.0096	24.9%	0.060	[0.0024]
	Stockton Area MS4	CAS083470	0.241	0.50	24.9%	0.060	[0.12]
Facilities	Manteca Aggregate Sand Plant	CA0082783	0.032	0.40	98.4%	0.032	[0.39]
	Deuel Vocational Inst. WWTP	CA0078093	0.020	0.013	100.0%	0.020	[0.013]
	City of Manteca WWTP	CA0081558	0.216	1.4	27.8%	0.060	[0.39]
	Mountain House CSD WWTP	CA0084271			*To be determined.*		
	City of Stockton WWTP	CA0079138	0.936	36	17.8%	0.167	6.4
	City of Tracy WWTP	CA0079154	0.146	1.9	41.1%	0.060	[0.8]
SAN JOAQUIN RIVER SUBAREA TOTAL:			**0.160**	**473**	**37%**	**0.060**	**175**

(d) Existing concentrations were rounded to three decimal places, and existing loads were rounded to two significant digits, before calculating acceptable concentrations and loads. Acceptable concentrations are provided to three decimal places for ease of verifying calculations. However, staff recommends that they be rounded to two decimal places to evaluate compliance.

(e) No load allocations are needed for sources with existing (e.g., Deuel Vocational Institute WWTP) or allocated (e.g., City of Manteca WWTP) discharge methylmercury concentrations at or below the implementation goal because the discharges act as dilution. However, the loads for such discharges are listed in brackets ("[ ]") in this table to enable the calculation of the percent allocations required for other sources to ultimately meet the implementation goal in ambient waters given current conditions. "Percent allocations" listed for these sources may be greater than for other sources because staff recommends that sources with existing average concentrations less the implementation goal maintain their existing concentration, and that no source discharge be required to reduce its discharge methylmercury concentrations to less than 0.06 ng/l during the first phase of the implementation program.

Table 8.3f: Allocations for Methylmercury Sources to the West Delta Subarea (a, b)

MeHg Sources	Tributary or Permittee	Permit #	Existing Average Annual MeHg Conc. (ng/l)	Existing Average Annual MeHg Load (g/yr)	Percent Allocation	Acceptable MeHg Conc. (g/yr)	Acceptable MeHg Load (g/yr)
BACKGROUND							
Atmospheric Deposition			*Not applicable.*	2.3	100%	*Not applicable.*	2.3
Sediment Flux	Open Water Habitats		*Not applicable.*	190	100%	*Not applicable.*	190
LOAD ALLOCATIONS							
Agricultural Drainage			0.352	4.1	100%	0.352	4.1
Sediment Flux	Wetland Habitats		*Not applicable.*	121	100%	*Not applicable.*	121
Urban (nps)			0.241	0.024	100%	0.241	0.024
WASTELOAD ALLOCATIONS							
MS4	County of Contra Costa	CAS083313	0.241	3.3	100%	0.241	3.3
WEST DELTA SUBAREA TOTAL:			**0.083** (a)	**128**	**100%**	**0.060** (a)	**128**

(a) Ambient methylmercury concentrations in the West Delta subarea approach the proposed aqueous methylmercury goal of 0.06 ng/l, resulting in the need for only modest reductions (28%) in methylmercury sources. The primary source of methylmercury in the West Delta subarea is sediment flux from open channel habitats, for which there is no responsible party yet identified. In addition, it is expected that, should the proposed reductions take place in sources to the upstream Delta subareas, the proposed aqueous goal will be met in the West Delta subarea. For example, the Sacramento subarea – the largest source of water to the West Delta subarea – requires a source reduction of 44%. Therefore, this TMDL proposes no net increase in methylmercury loading to the West Delta.

(b) Existing concentrations were rounded to three decimal places, and existing loads were rounded to two significant digits, before calculating acceptable concentrations and loads. Acceptable concentrations are provided to three decimal places for ease of verifying calculations. However, staff recommends that they be rounded to two decimal places to evaluate compliance.

Table 8.3g: Allocations for Methylmercury Sources to the Yolo Bypass Subarea (a)

MeHg Sources	Tributary or Permittee	Permit #	Existing Average Annual MeHg Conc. (ng/l)	Existing Average Annual MeHg Load (g/yr)	Percent Allocation	Acceptable MeHg Conc. (g/yr)	Acceptable MeHg Load (g/yr) (b)
BACKGROUND							
Atmospheric Deposition			*Not applicable.*	1.1	100%	*Not applicable.*	1.1
Sediment Flux	Open Water Habitats		*Not applicable.*	86	100%	*Not applicable.*	86
LOAD ALLOCATIONS							
Agricultural Drainage			0.352	19	17.0%	0.060	3.2
Sediment Flux	Wetland Habitats		*Not applicable.*	415	14.9%	*Not applicable.*	62
Tributary Inputs	Prospect Slough		0.424	537	14.9%	0.063	80
Tributary Inputs	Ulatis Creek (a)		0.240	8.9	25.0%	0.060	2.2
WASTELOAD ALLOCATIONS							
MS4	County of Solano	CAS000004	0.241	0.085	24.9%	0.060	0.021
MS4	County of Yolo	CAS000004	0.241	0.12	24.9%	0.060	0.030
MS4	City of West Sacramento	CAS000004	0.241	1.1	24.9%	0.060	0.27
YOLO BYPASS [North & South] SUBAREA TOTAL:			**0.273**	**1,068**	**22%**	**0.060**	**235**

(a) Existing concentrations were rounded to three decimal places, and existing loads were rounded to two significant digits, before calculating acceptable concentrations and loads. Acceptable concentrations are provided to three decimal places for ease of verifying calculations. However, staff recommends that they be rounded to two decimal places to evaluate compliance.

(b) No load allocations are needed for sources with allocated average discharge methylmercury concentrations at or below the implementation goal (e.g., City of West Sacramento) because the discharges act as dilution. However, the loads for such discharges are listed in brackets ("[ ]") in this table to enable the calculation of the percent allocations required for other sources to ultimately meet the implementation goal in ambient waters given current conditions. "Percent allocations" listed for these sources may be greater than for other sources because staff recommends that no source discharge be required to reduce its discharge methylmercury concentrations to less than 0.06 ng/l during the first phase of the implementation program.

8.2 Total Mercury Limits

Total mercury limits were developed for three reasons: (1) to maintain compliance with the USEPA's criterion of 50 ng/l for total mercury in the water column; (2) to prevent increases in total mercury discharges from causing increases in aqueous and fish methylmercury in the Delta, thereby worsening the impairment; and (3) to meet the San Francisco Bay TMDL allocation to the Central Valley. The TMDL for San Francisco Bay assigned the Central Valley a five-year average total mercury load allocation of 330 kg/yr or a decrease of 110 kg/yr (Section 2.4.2.3). A reduction of 110 kg/yr represents about a 28% decrease in the 20-year average annual loading[48] from Delta tributaries (Table 7.1). As described in Chapter 4 of the Proposed Basin Plan Amendment draft staff report, staff recommends that the 110 kg total mercury reduction be met by reductions in total mercury entering the Delta from the Sacramento Basin (Table 8.4). The reductions should occur in the Cache Creek, Feather River, American River and Putah Creek watersheds because these watersheds export the largest volume of highly contaminated sediment (Tables 7.5 and 7.17). Staff recommends that the proposed total mercury reductions for the Sacramento Basin tributaries be based on WY1984-2003 average annual loads. This 20-year period includes a mix of wet and dry years that is statistically similar to what has occurred in the Sacramento Basin over the last 100 years. The proposed reductions will enable Delta waters to maintain compliance with the CTR criterion of 50 ng/l (Section 7.4).

The Cache Creek Settling Basin is a 3,600-acre structure located at the base of the Cache Creek watershed.[49] The U.S. Army Corp of Engineers initially constructed the Settling Basin in 1937 to contain sediment and maintain the flood capacity of the Yolo Bypass. The CCSB was modified in 1993 to increase its sediment trapping efficiency. However, no provision was made for removing the additional trapped material. Most of the mercury in Cache Creek is transported on sediment. Therefore, an increase in sediment trapping also results in deposition and retention of mercury. The CCSB currently traps about 50% of the sediment and mercury transported by Cache Creek (Foe and Croyle, 1998; CDM, 2004; Cooke *et al.*, 2004). The rest is exported to the Delta through the Yolo Bypass. On average, the basin receives about 250 kg/yr from the Cache Creek watershed and discharges about 125 kg/yr to the Yolo Bypass. The sediment/mercury trapping efficiency of the Settling Basin is expected to decrease as the Basin fills and may reach zero in about 40 years unless a maintenance program is instituted to periodically remove material (CDM, 2004). A non-operational Settling Basin would result in a mercury discharge to the Yolo Bypass and Delta of about 250 kg/yr, an addition of 125 kg/yr mercury loading (Table 7.6b in the TMDL Report).

Staff recommends that total mercury loading from the Cache Creek Settling Basin be reduced by 72 kg/yr, resulting in an acceptable load to the Yolo Bypass and Delta of 53 kg/yr. This reduction is approximately 65% of the 110-kg/yr reduction required by the San Francisco Bay mercury TMDL. Two sets of actions are considered in the Proposed Basin Plan Amendment draft staff report (Chapter 4) for the Cache Creek Settling Basin to ensure that mercury loads to the Delta decrease. First, mercury loads entering the Basin from the Cache Creek watershed could be reduced. The Basin Plan Amendment for control of mercury in Cache Creek was adopted by the Central Valley Water Board in October 2005. Implementation actions described in the Basin Plan Amendment report would reduce mercury loads entering the Cache Creek Settling Basin by about 60 kg/year (Cooke and Morris, 2005), from 250 to

[48] Year-to-year loads are expected to fluctuate with water volume and other environmental factors.

[49] The Cache Creek Settling Basin is owned by local private landowners and the California Department of Water Resources.

Table 8.4: Total Mercury Load Limits for Sacramento Basin Tributaries

Tributary	Existing Annual TotHg Load [WY1984-2003] (a) (kg/yr)	TotHg Load Limit (b)	Acceptable TotHg Load (kg/yr)
Cache Creek	125	42%	53
American River	14	63%	66
Feather River	77		
Putah Creek	13		
TOTAL:	**229**	**48%**	**119**

(a) Existing annual TotHg loads represent the average annual loads estimated for WY1984-2003. This 20-year period includes a mix of wet and dry years that is statistically similar to what has occurred in the Sacramento Basin over the last 100 years. Annual loads are expected to fluctuate with water volume and other factors, but the limit as a percentage of a given load will not change as a function of these factors.

(b) These limits equate to a reduction of 110 kg/yr. Additional TotHg reductions may be recommended for the Delta's tributary watersheds in future phases of the Delta and tributary mercury control programs to address fish impairment in the Delta and/or upstream tributaries.

190 kg/yr. Approximately 25 kg of the 60 kg/year reduction in the Cache Creek watershed may come from instituting control programs at all major mercury mines in the watershed.[50] The remainder of the reduction will be achieved by control of erosion in mercury-enriched areas and by remediation/removal of contaminated floodplain sediment in the Cache Creek canyon and in Bear Creek. However, most the total mercury load now leaving the CCSB appears to originate from erosion of mercury contaminated sediment in the active flood plain downstream of the mines. Studies are required by the Cache Creek mercury control program to evaluate in-stream sediment control options. It is unclear whether environmentally acceptable, cost effective control programs can be developed to significantly curtail the movement of this material. As result, a second set of actions could focus on decreasing the mercury load leaving the CCSB. A program should be instituted to (a) periodically excavate the material presently accumulating in the basin, and (b) make additional modifications to the Basin to increase trapping efficiency. Initial modeling results indicate that Basin operation and design could be modified to remove up to an additional 55 kg/yr (CDM, 2004, Table 4-3, Alternative 5 - Excavate and Raise Weir Early), improving the trapping efficiency of the CCSB from 50% to 72%. Decreasing mercury inputs to the CCSB to 190 kg/yr through the watershed control program and increasing the trapping efficiency of the CCSB to 72% results in an export to the Yolo Bypass of 53 kg/yr, which represents a decrease of 72 kg/yr from current loading. Additional studies are underway to evaluate improvement options and costs.

The remaining 38 kg/yr reduction required to achieve a 110 kg/yr reduction in Central Valley total mercury loading is assigned to the sum of the mercury loads (104 kg/yr, Table 8.4) leaving the Feather River, American River and Putah Creek watersheds. This results in a reduction of 37% and an acceptable load of 64 kg/yr leaving these three watersheds. Monitoring is underway to identify sources of methyl and total mercury in these and the other Sacramento Basin tributary watersheds. Specific limits for the Feather River, American River and Putah Creek watersheds are not defined in Table 8.4 to allow for greater flexibility in developing future implementation strategies. However, the sum of the load reductions for these basins and Cache Creek Settling Basin must equal 110 kg/yr. Each of these watersheds contains waterways already identified on the CWQA Section 303(d) List as impaired by

[50] The mines are located in Harley Gulch, Sulfur and Bear Creeks and Clear Lake.

mercury. Hence, each will be the focus of future watershed-specific TMDL programs. Actual load reductions for each watershed will be specified in its TMDL report.

A 110 kg reduction in total mercury from the Sacramento Basin is a reasonable goal for the first phase of the Delta mercury control program. For example, Feather River and Cache Creek Settling Basin outflows have average methylmercury concentrations of 0.098 and 0.558 ng/l, respectively (see Appendix N for a summary of available methylmercury concentration data). If Feather River and Cache Creek Settling Basin outflows needed to meet the proposed implementation goal for the Delta of 0.06 ng/l to enable achievement of the aqueous methylmercury goal in the Sacramento River and Yolo Bypass inputs to the Delta, they would require methylmercury load reductions of 39% and 89%, respectively. If the proposed source characterization and control studies find no means to reduce aqueous methylmercury by methods other than total mercury reduction, than the total mercury exports from the Feather River (77 kg/yr) and CCSB (125 kg) may require reductions of a similar magnitude. A 39% reduction of Feather River watershed total mercury outflows is about 30 kg/yr, and an 89% reduction of CCSB exports is about 110 kg/yr, totaling about 140 kg/yr.

Anticipated population growth and regional hydrologic changes that may result from global climate changes could result in increases in total mercury loading. As described in Sections 2.2.1 and 8.4.3.1, rapid growth is occurring in urban areas in and surrounding the Delta. There are numerous NPDES-permitted facilities and MS4s that discharge mercury to the Delta and its tributary watersheds. These discharges are expected to increase with increased population growth. In addition, changes to reservoir and flood control operations could result in changes in mercury loading to the Delta. As described in Chapter 4 of the Proposed Basin Plan Amendment draft staff report, staff recommends that total mercury loading to the Delta not increase as a result of new or expanded projects, and that any increase in total mercury loading be mitigated or in compliance with an offset program.

There is a need for a mercury control program that is consistent in addressing NPDES permits within and adjacent to the Delta. For example, applying different regulations to a given MS4 service area split by the legal Delta boundary would be ineffective and difficult to implement. Therefore, it may be more efficient to implement controls on both within-Delta and upstream sources as part of the Delta implementation plan, to the extent justified by available information. The alternatives analysis in Chapter 4 of the Proposed Basin Plan Amendment draft staff report identified a scope that includes NPDES permits downstream of major dams[51] as the preferred option because: (a) dams on the major tributaries act as constraints on water volumes and total mercury loading from the upper watersheds; and (b) total mercury discharges in the tributaries are expected to eventually be transported to the Delta.

Power, heating/cooling and aquaculture facilities, which account for about 50% of the volume discharged by facilities to the Delta source region, do not appear to add measurable amounts of total mercury to the water that they withdraw from Delta waterways (see Section 7.1.2 and Appendix G). This consideration will be re-evaluated as additional information becomes available. In addition, facilities that discharge greater than 1 mgd account for about 97% of the volume discharged by facilities to the Delta source region. Therefore, total mercury limits do not apply to power, heating/cooling and aquaculture facilities

[51] Major reservoirs and lakes in the Sacramento Basin include Shasta, Whiskeytown, Oroville, Englebright, Camp Far West, Folsom/Natoma, and Black Butte, Indian Valley, Clear Lake and Lake Berryessa. Major reservoirs and lakes in the San Joaquin Basin include Camanche, New Hogan, New Melones/Tulloch, Don Pedro, McClure, Burns, Owens, Eastman, Hensley, Millerton and Marsh Creek.

or to facilities that discharge less than 1 mgd. Staff recommends that the annual load of total mercury from all NPDES facilities that discharge greater than 1 mgd in the Delta and its tributary watersheds downstream of major dams be capped at their 2008 loading rate; a mercury offset program is anticipated for Central Valley Water Board consideration in 2009.

Staff recommends that the annual load of total mercury from all MS4 service areas in the Delta and its tributary watersheds downstream of major dams be capped at their 2014 loading rate, a delayed cap to allow adequate time to conduct total mercury characterization and control studies.

Tables 8.5 and 8.6 list the permitted facilities and MS4s within the Delta and its tributary watersheds downstream of major dams for which the total mercury limits would apply. The Central Valley Water Board will evaluate several alternatives to ultimately determine the scope of the Delta mercury control program.

8.3 Margin of Safety

Implicit and explicit margins of safety are included in the aqueous methylmercury goal for the Delta. In addition, while not a direct margin of safety, the implementation plan (Chapter 4 in the Proposed Basin Plan Amendment draft staff report) calls for updated fish advisories in the Delta and an expanded outreach program to educate humans fishing in the Delta.

The proposed aqueous methylmercury goal of 0.06 ng/l (Chapter 5) incorporates an explicit margin of safety of approximately 10%. The linkage analysis (Section 5.2) predicted a safe level of 0.066 ng/l for average aqueous methylmercury, from which 0.006 was subtracted to provide a margin of safety.

In addition, there is an implicit margin of safety for wildlife species that consume Delta fish. As outlined in the previous paragraph, the aqueous methylmercury goal corresponds to 0.24 mg/kg mercury in large TL4 fish, which was calculated for the protection of humans consuming about one meal per week. As shown in Table 4.9 (Chapter 4), the wildlife targets for smaller and lower trophic level fish correspond to large TL4 fish mercury levels that range from 0.30 mg/kg (for Western grebe) to 1.12 mg/kg (for Western snowy plover). These values correspond to 350-mm largemouth bass mercury levels of 0.31 and 1.34 mg/kg. When entered into the regression equation for largemouth bass and unfiltered average aqueous methylmercury (Figure 5.2[A]), these values translate to aqueous methylmercury concentrations of 0.08 ng/l and 0.19 ng/l, allowing a margin of safety of 25% or more, depending on the wildlife species.

Table 8.5: NPDES Permitted Facilities in the Delta and its Tributary Watersheds Downstream of Major Dams for Which 2008 Total Mercury Load Limits Are Recommended

Facility (NPDES No.)	Facility (NPDES No.)
Facilities within the Delta	
Brentwood WWTP (CA0082660) Discovery Bay WWTP (CA0078590) Lodi White Slough WWTP (CA0079243) Manteca Aggregate Sand Plant (CA0082783) Manteca WWTP (CA0081558) Mountain House CSD WWTP (CA0084271)	Sacramento Combined WWTP (CA0079111) SRCSD Sacramento River WWTP (CA0077682) Stockton WWTP (CA0079138) Tracy WWTP (CA0079154) West Sacramento WWTP (CA0079171)
Facilities in the Tributary Watersheds Downstream of Major Dams	
Aerojet Interim Groundwater Treatment Plant (CA0083861) Anderson WPCP (CA0077704) Atwater WWTF (CA0079197) Auburn WWTP (CA0077712) Boeing Company Interim Treatment System (CA0084891) Chico Regional WWTF (CA0079081) Corning Industries/ Domestic WWTF (CA0004995) Davis WTP (CA0079049) Defense Logistics Agency Sharpe Groundwater Cleanup (CA0081931) El Dorado Irrigation District Deer Creek WWTP (CA0078662) El Dorado Irrigation District El Dorado Hills WWTP (CA0078671) Galt WWTP (CA0081434) General Electric Co. GWCS (CA0081833) Hershey Chocolate USA, Oakdale (CA0004146) J.F. Shea Co Fawndale Rock and Asphalt (CA0083097) Lincoln WWTP (CA0084476) Linda Co Water Dist WPCP (CA0079651)	Live Oak (CA0079022) Merced WWTF (CA0079219) Modesto WQCF (CA0079103) Olivehurst PUD WWTP (CA0077836) Oroville WWTP (CA0079235) Pactiv Molded Pulp Mill (CA0004821) Placer Co. SMD #1 WWTP (CA0079316) Proctor & Gamble Co. WWTP (CA0004316) Red Bluff WWRP (CA0078891) Redding Clear Creek WWTP (CA0079731) Redding Stillwater WWTP (CA0082589) Roseville Dry Creek WTP (CA0079502) Roseville Pleasant Grove WTP (CA0084573) Turlock WWTP (CA0078948) University of California, Davis WTP (CA0077895) U.S. Air Force McClellan Air Force Base Groundwater Extraction & Treatment System (CA0081850) Vacaville Easterly Sewage Plant (CA0077691) Woodland WWTP (CA0077950) Yuba City WW Reclamation Plant (CA0079260)

Table 8.6: MS4s in the Delta and its Tributary Watersheds Downstream of Major Dams for Which 2014 Total Mercury Load Limits Are Recommended (a)

MS4 (NPDES No.)	Phase	MS4 (NPDES No.)	Phase
MS4s within the Delta			
Contra Costa (County of) (CAS083313)	I	San Joaquin (County of) (CAS000004)	II
Lathrop (City of) (CAS000004)	I	Solano (County of) (CAS000004)	II
Lodi (City of) (CAS000004)	II	Stockton Area MS4 (CAS083470)	I
Port of Stockton MS4 (CAS084077)	I	Tracy (City of) (CAS000004)	II
Rio Vista (City of) (CAS000004)	II	West Sacramento (City of) (CAS000004)	II
Sacramento Area MS4 (CAS082597)	I	Yolo (County of) (CAS000004)	II
MS4s in the Tributary Watersheds Downstream of Major Dams			
Butte (County of) (CAS000004)	II	Ripon (City of) (CAS000004)	II
Ceres (City of) (CAS000004)	II	Riverbank (City of) (CAS000004)	II
Chico (City of) (CAS000004)	II	Rocklin (City of) (CAS000004)	II
Contra Costa (County of) (CAS083313)	I	Roseville (City of) (CAS000004)	II
Dixon (City of) (CAS000004)	II	Sacramento Area MS4 (CAS082597)	I
Hughson (City of) (CAS000004)	II	San Joaquin (County of) (CAS000004)	II
Lathrop (City of) (CAS000004)	II	Solano (County of) (CAS000004)	II
Lincoln (City of) (CAS000004)	II	Stanislaus (County of) (CAS000004)	II
Lodi (City of) (CAS000004)	II	Stockton Area MS4 (CAS083470)	I
Loomis (City of) (CAS000004)	II	Sutter (County of) (CAS000004)	II
Manteca (City of) (CAS000004)	II	Tracy (City of) (CAS000004)	II
Marysville (City of) (CAS000004)	II	Turlock (City of) (CAS000004)	II
Modesto (City of) (CAS083526)	I	Vacaville (City of) (CAS000004)	II
Oakdale (City of) (CAS000004)	II	West Sacramento (City of) (CAS000004)	II
Patterson (City of) (CAS000004)	II	Yolo (County of) (CAS000004)	II
Port of Stockton MS4 (CAS084077)	I	Yuba City (City of) (CAS000004)	II

(a) Including Caltrans Statewide permit #CAS000003.

8.4 Seasonal & Inter-annual Variability

8.4.1 Variability in Aqueous Methyl and Total Mercury

Mercury loads in Delta tributary inputs fluctuate because of seasonal and inter-annual variation. Winter precipitation increases the sediment and total mercury loads entering the Delta through erosion and resuspension of sediment. Most of the total mercury coming from tributaries and direct surface runoff enters the Delta during high flow events. In contrast, methylmercury production is typically higher during the summer months. In addition, greater mercury loads enter the Delta during wet water years.

Seasonal and inter-annual variability in methylmercury loads were accounted for in the source analysis and methylmercury load allocations by evaluating annual average loads for Delta sources and losses for WY2000 to 2003, a relatively dry period that encompasses the available concentration data for the major Delta inputs and exports. Twenty-year average, annual loads of total mercury were estimated for tributary loads based on flow and precipitation records for WY1984-2003. This 20-year period includes a mix of wet and dry years that is statistically similar to what has occurred in the Sacramento Basin over the last 100 years. However, insufficient data were available to estimate 20-year average annual loads for methylmercury sources. Methylmercury allocations and total mercury limits will be re-evaluated as additional information becomes available. Future monitoring programs will accommodate long-term inter-annual variability by evaluating whether sources are meeting allocations on a multi-year basis.

8.4.2 Variability in Biota Mercury

Seasonal and inter-annual variation also occurs in biota. Slotton and others (2003) found that Delta species exhibited both seasonal and inter-annual variability in mercury body burden. Corbicula (clams) had higher mercury concentrations in the spring while inland silversides (representative forage fish species) were higher in fall. In addition, silverside bioaccumulation was greater in 1998 than in 1999 and 2000 at many locations in the Delta. Davis and others (2002) measured higher mercury concentrations in similar sized largemouth bass in 1999 than in 2000. The researchers noted that the winter of 1997 was very wet and speculated that the high flows may have introduced significant quantities of "new" mercury that was methylated and incorporated into forage fish in 1998. Predacious fish like largemouth bass, which feed upon silversides, took an additional year to reflect the higher methylmercury concentrations.

Seasonal and inter-annual variability in large fish was accounted for in the numeric targets and linkage analysis by using data collected over multiple years. Future monitoring will accommodate seasonal and inter-annual variability by sampling large fish about every five years.

8.4.3 Regional and Global Change

Several ongoing regional and global changes may affect methyl and total mercury loading in the Delta. This section identifies several of these.

8.4.3.1 Population Growth

The Delta and its tributary Sacramento and San Joaquin watersheds are experiencing substantial population growth. Populations in both basins increased by about 18% between 1990 and 2000 (AFT, 2004; CDOF, 2004). This resulted in the conversion of about 55,000 acres of agricultural land to urban uses (AFT, 2004). Four of the five fastest growing cities in the Sacramento Valley are located within about one day's travel time (about 20 to 30 miles by water) of the Delta. The California Department of Finance predicts that populations in the Delta and immediately adjoining counties will increase 130 to 200% by 2050 (CDOF, 2004).

Urbanization increases both volume and discharge velocity of runoff because of the increase in impervious surfaces. In addition, urbanization tends to increase pollutant loading because impervious surfaces neither absorb water nor remove pollutants, and urban development tends to create new anthropogenic mercury pollution sources. As Chapter 7 indicates, urban runoff in the Sacramento, Stockton and Tracy areas has higher total mercury concentrations than ambient river concentrations. However, little is known about how the conversion of agricultural land to urban uses affects methylmercury concentration. Chapter 4 in the Proposed Basin Plan Amendment draft staff report reviews possible implementation strategies to address the methylmercury allocations and total mercury limits for urban areas in the Delta region.

8.4.3.2 Restoration of Wetlands

Research conducted in the Delta and elsewhere has found that wetlands are efficient sites for methylmercury production. The Record of Decision for the CALFED Bay-Delta Program commits it to restore about 40,000 acres of seasonal and permanent wetlands in the Delta during the next 30 years (CALFED Bay-Delta Program, 2000c). Methylmercury production estimates from experimental marshes and open water habitat in the Delta suggest that this amount of new wetland may result in about a 50% increase in methylmercury loading from sediment during low flow periods (Heim *et al.*, 2004). Mass balance calculations indicated that sediment flux during this time may account for approximately 1,149 g/year of MeHg (Table 6.2 and 6.4 and Figure 6.11), or about 23% of the total methylmercury budget for the Delta (4,922 g/yr; Table 6.2). A 50% increase in methylmercury from sediment would increase overall Delta loading by about 12%. The linkage relationship suggests that a 12% increase in aqueous methylmercury loads could result in up to a 20% increase in mercury concentrations in standard 350-mm largemouth bass (Figure 5.3). Chapter 4 in the Proposed Basin Plan Amendment draft staff report provides a description of staff's suggested Central Valley Water Board policy for new wetland creation.

8.4.3.3 Decreasing Sediment Loads

The sediment load in the Sacramento River decreased by about 50% between 1957 and 2001 (Wright & Schoellhamer, 2004). The decrease is believed to be caused by the trapping of sediment in reservoirs, a decrease in erodable material from hydraulic mining, changes in land use, and construction of levees (Wright & Schoellhamer, 2004; James, 2004). Mercury loads are likely to have also decreased during the same time period as much of the inorganic mercury is transported on sediment particles. It is not known what the magnitude of the decrease in mercury loading has been and whether it will continue in the future. The decrease in sediment loading suggests that the relative proportion of erodable material from upstream watersheds may also be changing. The present 20-year volume-weighted average mercury to TSS ratio of sediment entering the Delta is approximately 0.18 mg/kg. This value may change depending on the new sources of sediment. The mercury content of surficial sediment is important, as it is one of the major factors controlling methylmercury production. Methylmercury production in Delta sediment now accounts for about 30% of the methylmercury in the Delta (Figure 6.11). It is not clear how this proportion may change in the future.

8.4.3.4 Climate Change

Recent studies indicate that global warming may disrupt traditional weather and run-off patterns and increase the frequency and severity of summer droughts and springtime flooding (Brekke *et al.*, 2004; Knowles and Cayan, 2002; Miller *et al.*, 2003; Service, 2004; Stewart *et al.*, 2004). Trends over the last 50 years indicate that more precipitation in the Sierra Nevada Mountains is occurring as rain, and that snow is melting earlier in the spring, resulting in a reduced snow pack and less water in reservoirs in the summer and fall. Climate models suggest that these trends may become more pronounced with continued warming. The net result may have unpredictable consequences on ecological processes in the Delta including the synthesis and bioaccumulation of methylmercury. The source analyses, linkage analysis, methylmercury allocations and total mercury limits described in this TMDL are based on present climate. Staff will re-evaluate linkage relationships associated with changing environmental conditions as more information becomes available in the future.

Key points and options to consider are summarized on the following two pages.

Key Points

- Methylmercury allocations are divided among "wasteload allocations" for point sources and "load allocations" for nonpoint sources. The TMDL is the sum of these components. The allocation strategies described in this report are an initial proposal to address the beneficial use impairment in all subareas of the Delta. Total mercury limits were developed to maintain compliance with the USEPA's CTR for total mercury in the water column and to achieve the San Francisco Bay mercury control program's total mercury allocation for the Central Valley.

Methylmercury:

- Methylmercury allocations were made in terms of the existing assimilative capacity of the different Delta subareas. The recommended goal for ambient water is an average annual concentration of 0.06 ng/l methylmercury in unfiltered water (Chapter 5). This goal describes the assimilative capacity of Delta waters in terms of concentration and encompasses a margin of safety of approximately 10%. Central Valley Water Board staff anticipates that as the average concentration of methylmercury in each Delta subarea decreases to the safe aqueous goal, the targets for fish tissue will be attained.
- To determine necessary reductions, the existing average aqueous methylmercury levels in ambient water in the Delta subareas were compared to the methylmercury goal. The amount of reduction needed in each subarea is expressed as a percent of the existing concentration. Percent reductions required to meet the goal ranged from 0% in the Central Delta subarea to more than 70% in the Yolo Bypass and Mokelumne River subareas.
- Central Valley Water Board staff recommends that sources with existing or allocated average methylmercury concentrations at or below 0.06 ng/l be considered dilution and assigned no net increase in methylmercury concentration.

Total Mercury:

- Central Valley Water Board staff recommends that the 110 kg total mercury reduction allocated by the San Francisco Bay mercury control program to the Central Valley be met by reductions in total mercury entering the Delta from the Cache Creek, Feather River, American River and Putah Creek watersheds in the Sacramento Basin. These watersheds have both relatively large mercury loadings and high mercury to TSS ratios, which makes them likely candidates for load reduction programs. All other tributary watershed and within-Delta point sources were assigned no net increase in total mercury loading. Additional reductions may be recommended in future phases of the Delta mercury implementation program to meet the proposed methylmercury goal for ambient Delta waters.

Options to Consider

- The methylmercury allocations described in this chapter reflect the preferred implementation alternative described in Chapter 4 of the Proposed Basin Plan Amendment draft staff report and are designed to address the beneficial use impairment in all subareas of the Delta. However, as described in the draft Basin Plan Amendment report, a number of alternatives are possible. The Central Valley Water Board will consider a variety of allocation strategies and implementation alternatives as part of the Basin Plan amendment process.
- Likewise, a variety of total mercury reduction strategies are possible. A total mercury load reduction strategy was developed to comply with the San Francisco Bay mercury TMDL allocation for to the Central Valley and the USEPA's criterion for human health protection, and to help enable methylmercury reductions in Delta water and fish. Staff applied the San Francisco Bay TMDL's allocated reduction of 110 kg total mercury reduction to loads from the Cache Creek, Feather River, American River and Putah Creek watersheds because these watersheds export the largest volume of highly contaminated sediment while within-Delta sources comprise only a couple percent of total mercury inputs. An alternate strategy could be to apply equal percent reductions to all within-Delta and tributary source loads.
- Most sources of total mercury in the Delta and its tributary watersheds are not expected to increase in the future, except for sources related to population growth: industrial and municipal wastewater treatment plant and MS4 discharges. The strategy recommended in this report assigns total mercury limits to the NPDES facilities and MS4 service areas in the tributary watersheds downstream of major dams. Another approach could be to assign limits to those discharges in watersheds with TMDLs planned when TMDL development takes place, and to assign limits during Phase II of the proposed implementation plan (see Chapter 4 of the Proposed Basin Plan Amendment draft staff report) to those watersheds with no TMDLs currently planned. The Central Valley Water Board will consider a variety of strategies as part of the final Basin Plan amendment process.

9 PUBLIC OUTREACH

Central Valley Water Board staff received information from numerous agencies including USEPA, USGS, USBR, UC Davis, SFEI, SRWP, Delta Tributaries Mercury Council (DTMC) and CALFED and from the public. Staff has solicited and will continue to solicit public participation by:

- Sending notification of availability of the draft TMDL Report to interested parties (e.g., federal, state and local agencies involved in the watershed, NPDES facilities, members of local watershed groups, the DTMC and other interested persons). The draft TMDL report and appendices will be available in PDF format on the Central Valley Water Board website: http://www.waterboards.ca.gov/centralvalley/programs/tmdl/deltahg.html. Paper copies of the report will be sent to interested persons upon request.
- Soliciting and reviewing the public's written and verbal comments.
- Holding a CEQA scoping meeting and Board Workshop and organizing public meetings within the Delta watershed to explain the TMDL and Proposed Basin Plan Amendment draft staff report and to receive and respond to comments.
- Continuing to coordinate with and receive input from dischargers, agencies, the DTMC, and interested persons.

Central Valley Water Board staff will consider relevant comments and any additional data in the final version of the TMDL report and the Proposed Basin Plan Amendment staff report for the Delta. Central Valley Water Board staff will solicit written and oral comments from the public on the Proposed Basin Plan Amendment draft staff report and revised TMDL report, prepare responses, and submit the comments and responses to the Central Valley Water Board.

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