Draft Staff Report for Scientific Peer Review for the Amendment to the Water Quality Control Plan for Inland Surface Waters, Enclosed Bays, and Estuaries of California, Mercury Reservoir Provisions — Mercury TMDL and Implementation Program for Reservoirs

Statewide Mercury Control Program for Reservoirs

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CALIFORNIA
Water Boards
STATE WATER RESOURCES CONTROL BOARD
REGIONAL WATER QUALITY CONTROL BOARDS

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

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Figures are provided in a separate Adobe Acrobat (PDF) file.

LIST OF APPENDICES

Appendices are provided in a separate folder.

ACRONYMS AND TERMS

§	Section
303(d) List	List of “impaired” waters not meeting water quality standards; see section 1.4.3 for information on Clean Water Act section 303(d), the listing process, and the California Integrated Report.
AWQC	Ambient water quality criterion
BAF	Bioaccumulation factor
Basin Plan	Water Quality Control Plan
BSAF	Biota-Sediment Accumulation Factor
bwt	Body weight
CARB	California Air Resources Board
CDEC	California Data Exchange Center
CDFW	California Department of Fish and Wildlife
CDOC	California Department of Conservation
CDPH	California Department of Public Health
CEDEN	California Environmental Data Exchange Network
CEQA	California Environmental Quality Act
CFR	Code of Federal Regulations
CIWQS	California Integrated Water Quality System
COMM	Commercial and Sport Fishing (COMM) beneficial use
CTR	California Toxics Rule
DWR	Department of Water Resources
FERC	Federal Energy Regulatory Commission
GIS	Geographic Information System
Hg	Mercury
MDL	Method detection limit
MeHg	Methylmercury

MQL	Method quantitation limit
MRDS	USGS's Mineral Resources Data System
MS4	Municipal separate storm sewer system
NEL	Numeric Effluent Limitation
NPDES	National Pollutant Discharge Elimination System
NTR	National Toxics Rule
OEHHA	Office of Environmental Health Hazard Assessment
RARE	Rare, Threatened, or Endangered Species (RARE) beneficial use
Regional Water Board(s)	Refers to one or more of the nine Regional Water Quality Control Boards
REMSAD	Regional Modeling System for Aerosols and Deposition
Reservoir Mercury TMDL	One element of the Mercury Reservoir Provisions is the Reservoir Mercury TMDL, which applies to mercury-impaired reservoirs (see Chapter 1)
State Water Board	Refers to the State Water Resources Control Board
SWAMP	Surface Water Ambient Monitoring Program
TL	Trophic level
TMDL	Total Maximum Daily Load
USACE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation
USEPA	United States Environmental Protection Agency
USGS	United States Geologic Survey
Water Boards	Refers collectively to the nine Regional Water Quality Control Boards (Regional Water Boards) and the State Water Resources Control Board (State Water Board).
WDR	Waste Discharge Requirements
WILD	Wildlife Habitat (WILD) beneficial use
WLA	Waste Load Allocation
WWTP	Waste water treatment plant

UNITS OF MEASURE

Chl/L	microgram chlorophyll per liter
cfs	cubic feet per second
cm	centimeter
cm^2/s	square centimeter per second
dw	dry weight
g	gram
$g/km^2/yr$	gram per square kilometer per year
g/year	gram per year
g/day	gram per day
µg	microgram
µg/g	microgram per gram
µg/L	microgram per liter
µm	micrometer
L/kg	liter per kilogram
mg/kg	milligram per kilogram
M-kg	million kilograms
MGD	million gallons per day
ng	nanogram
ng/L	nanogram per liter
ppm	part per million
ww	wet weight

LIST OF PLANNED COMPANION DOCUMENTS FOR THE STATEWIDE MERCURY CONTROL PROGRAM FOR RESERVOIRS

All documents will be available on the State Water Board website:
http://www.waterboards.ca.gov/water_issues/programs/mercury/reservoirs/

The package for scientific peer review consists of the following documents:

- Transmittal letter to scientific peer reviewers, which includes "Description of Scientific Conclusions to be Evaluated by Scientific Peer Reviewers"
- Rule language:
  - Amendment to the Water Quality Control Plan for Inland Surface Waters, Enclosed Bays, and Estuaries of California—Mercury TMDL and Implementation Program for Reservoirs (hereinafter, Mercury Reservoir Provisions)
- Supporting staff report:
  - Draft Staff Report for Scientific Peer Review for the Amendment to the Water Quality Control Plan for Inland Surface Waters, Enclosed Bays, and Estuaries of California, Mercury Reservoir Provisions—Mercury TMDL and Implementation Program for Reservoirs

After scientific peer review, the next package will be draft documents for public review.

Staff will review and respond to comments from scientific peer reviewers, and if needed, revise the previously described documents. The future package for public review will also address some regulatory topics not included in the package for scientific peer review, such as the following:

- Environmental analysis in accordance with the California Environmental Quality Act (CEQA)
  - Project description, objectives, CEQA environmental checklist, and discussion
  - Review of and compliance with existing federal and state regulations, policies, and habitat conservation plans
  - Alternatives analysis
  - Evaluation of economic factors per Public Resources Code section 21159
- Scientific peer reviewer comments and staff responses
  - Transmittal letters to scientific peer reviewers; reviewer comments; staff responses to comments; and if applicable, an explanation of how the regulatory language and staff reports were revised

Lastly, final proposed documents will be prepared and submitted to the State Water Resources Control Board for consideration of adoption.

Staff will review and respond to written public comments, and if needed, revise the documents listed previously. The proposed final package for consideration by the State Water Board will also include the following:

- Proposed resolution adopting amendments to the Water Quality Control Plan for Inland Surface Waters, Enclosed Bays, and Estuaries of California—Mercury TMDL and Implementation Program for Reservoirs

- Written stakeholder comments and staff responses and if applicable, an explanation of how the regulatory language and staff reports were revised

A related statewide project is also underway.

The State Water Resources Control Board is proposing Part 2 of the Water Quality Control Plan for Inland Surface Waters, Enclosed Bays, and Estuaries of California—Tribal and Subsistence Fishing Beneficial Uses and Mercury Provisions (Provisions). The Provisions would establish the following elements:

- Three beneficial use definitions pertaining to tribal traditional and cultural use, tribal subsistence fishing use, and subsistence fishing use by other cultures or individuals;
- One narrative and four numeric mercury water quality objectives to protect numerous beneficial uses of water involving human health and aquatic dependent wildlife; and
- A program of implementation to control mercury discharges.
- Information about these projects is available at: http://www.waterboards.ca.gov/water_issues/programs/mercury/

RECOMMENDED FORMAT FOR SCIENTIFIC PEER REVIEWER'S COMMENTS

Message to scientific peer reviewers:

Water Board staff requests that written comments include references, as appropriate, to this Staff Report's page and line number. For comments that address overarching issues, please include reference to applicable chapter numbers.

SUMMARY

This summary provides a plain-language overview of the Statewide Mercury Control Program for Reservoirs.

The Water Boards recognize that reservoirs are vital to California and that reservoir operations face challenges from floods, droughts, and climate change. Especially in response to challenges posed by climate change, reservoir operators will likely need to nimbly manage water chemistry that could change from year-to-year. Therefore, this mercury program addresses controllable water quality factors and does not impose any restrictions on water supply.

In the first decade, reservoir owners and operators would test feasible reservoir management actions. The Water Boards encourage a coordinated approach for fewer, focused tests rather than tests in all mercury-impaired reservoirs. The test results will be evaluated by an independent, third-party Technical Review Committee before the Water Boards would develop long term requirements for all mercury-impaired reservoirs.

While the reservoir testing program is underway, the Water Boards will ensure that mercury sources are controlled to all mercury-impaired reservoirs.

S-1 Problem Statement, Goals, and Scope

Problem statement

Harmful levels of methylmercury in fish are a statewide and nationwide problem. Mercury is a bioaccumulative toxic pollutant that results in many reservoir fish having methylmercury levels that pose a risk for humans and wildlife that eat the fish. Mercury does not impair drinking water quality in California reservoirs. The number of reservoirs determined to be impaired by mercury is expected to increase substantially as new fish tissue monitoring data are collected and evaluated. The Statewide Mercury Control Program for Reservoirs applies to the mercury-impaired reservoirs listed on Table S-2. Elevated fish methylmercury levels impair the following beneficial uses: commercial and sport fishing (COMM), wildlife habitat (WILD), and preservation of rare and endangered species (RARE).

Goals

To address the mercury problem in reservoirs, the State Water Resources Control Board (State Water Board) has undertaken a statewide program ("Statewide Mercury Control Program for Reservoirs"), which has the following main goals:

1. Reduce fish methylmercury concentrations in reservoirs that have already been determined to be mercury-impaired;
2. Have a control program in place that will apply to additional reservoirs when they are determined in the future to be mercury-impaired; and
3. Protect additional reservoirs from becoming mercury-impaired.

To achieve these goals, the State Water Board is proposing to establish a rule titled, "Amendment to the Water Quality Control Plan for Inland Surface Waters, Enclosed Bays, and Estuaries of California—Mercury TMDL and Implementation Program for Reservoirs" (hereinafter, Mercury Reservoir Provisions).

Scope

The Mercury Reservoir Provisions include several key elements. The first element is a program of implementation for achieving and maintaining mercury water quality objectives (see below) in reservoirs. The program of implementation includes control actions for (1) point and nonpoint sources of mercury, and pilot tests for (2) reservoir water chemistry to reduce methylmercury production and (3) fisheries management to reduce methylmercury bioaccumulation.

The second element consists of recommendations (1) to protect people who eat mercury-contaminated reservoir fish while pilot tests are underway and inorganic mercury source reductions are occurring, (2) directed to the California Department of Fish and Wildlife for fisheries management, and (3) directed to other agencies to ensure reductions in atmospheric mercury.

The third element is a "total maximum daily load" for mercury-impaired reservoirs (Reservoir Mercury TMDL).

S-2 Reservoir Definition

For this program, a reservoir is defined as a natural or artificial water impoundment that:

- Has constructed structures such as dams, levees, or berms to contain or otherwise manage water, and/or was excavated; and
- Provides year round habitat for fish other than those specifically introduced for vector control purposes.

Several types of impoundments are excluded, such as the following: potable water storage; industrial and mining supply water storage; wastewater treatment and storage; basins filled intermittently for flood control; and agricultural and ranching ponds.

S-3 Water Quality Objectives

There is a related but separate mercury water quality objectives project (see *link*) that includes several objectives to protect human and wildlife health for consumption of fish. These objectives will apply to reservoirs addressed by the Statewide Mercury Control Program for Reservoirs. Mercury water quality objectives are proposed for sport fish, prey fish, and small prey fish where least tern habitat is supported. However, only one or two of these three mercury objectives apply to any particular water body, including to reservoirs (see Table S-1).

The "sport fish objective" protects humans and applies to all reservoirs to protect wildlife. Average methylmercury concentrations should not exceed 0.2 milligrams of methylmercury per kilogram of fish (mg/kg wet weight). This objective protects humans for consumption of one meal per week of fairly large fish (i.e., legal size catch).

One of two prey fish objectives may apply to each reservoir to protect wildlife that eats very small fish (see Table S-1). If a reservoir supports California least tern habitat, then the "CA least tern objective" applies; average methylmercury concentrations should not exceed 0.03 mg/kg. If a reservoir does not support California least tern habitat, then the "prey fish objective" would apply; average methylmercury concentrations should not exceed 0.05 mg/kg.

S-4 Implementation Plan

Achieve all applicable targets

One or two TMDL targets (see S-7) are applicable to each mercury-impaired reservoir. (These TMDL targets correspond to the one or two mercury water quality objectives applicable to each reservoir.) This implementation plan is designed to achieve all applicable targets in mercury-impaired reservoirs.

Phases and program review

Implementation would occur over two phases. Table S-2 lists the mercury-impaired reservoirs that would be included in Phase 1 and mercury-impaired reservoirs with Federal Energy Regulatory Commission hydropower licenses that would be addressed in the future. Phase 1 is expected to last for 10 years, after which the State Water Board will conduct a program review.

This program review will determine effective and feasible reservoir management actions based on results of the reservoir pilot tests (described below) and will develop Phase 2 implementation requirements. In Phase 2, requirements would be applied to additional reservoirs and corresponding mercury sources as the reservoirs are determined to be mercury-impaired by the Water Boards[1]. Initiating Phase 2 would require a future amendment to the Water Quality Control Plan for Inland Surface Waters, Enclosed Bays, and Estuaries of California.

[1] "Water Boards" refers collectively to the State Water Board and nine Regional Water Quality Control Boards.

Reservoirs and mercury control actions

The mercury control actions apply to different sets of reservoirs as follows:

- Mercury source control actions for dredging and studies needed for atmospheric deposition apply statewide;
- Recommendations for exposure reduction apply to all reservoirs and are particularly needed for impaired reservoirs;
- Control actions apply to many mercury sources upstream of impaired reservoirs; sources such as mines, urban runoff (storm water), and municipal and industrial facility discharges (non-stormwater).
- In Phase 1, reservoir water chemistry and fisheries management pilot tests apply to mercury-impaired reservoirs that do not have a Federal Energy Regulatory Commission hydropower license; and
- Mercury source and methylation control actions for new reservoirs.

Effective date

After the State Water Board adopts the Mercury Reservoir Provisions, the Mercury Reservoir Provisions are effective upon approval by the California Office of Administrative Law. The effective date is the beginning of Phase 1.

Applicability to existing mercury TMDLs

The Reservoir Mercury TMDL will not apply to Clear Lake (Lake County), Soulajule Reservoir (Marin County), and Guadalupe River Watershed (Santa Clara County) reservoirs downstream of Vasona Dam or downstream of New Almaden mining district because mercury TMDLs were previously adopted by the Regional Water Boards for these reservoirs.

In contrast, the Reservoir Mercury TMDL will supersede the mercury TMDL for Hernandez Reservoir previously adopted by the Central Coast Regional Water Board. Additionally, both the Reservoir Mercury TMDL and USEPA-established mercury TMDLs (in the Los Angeles Area Lakes TMDL for nitrogen, phosphorus, mercury, trash, organochlorine pesticides, and PCBs) will apply to the El Dorado Park Lakes, Puddingstone Reservoir, and Lake Sherwood.

S-5 Key Actions in Phase 1

Reservoirs: Pilot tests

Owners and operators of mercury-impaired reservoirs (see Table S-2) would conduct pilot tests of methods to reduce methylmercury concentrations in reservoir fish. Hydroelectric power reservoirs (i.e., licensed by Federal Energy Regulatory Commission) would be excluded from mercury pilot test requirements in Phase 1. Coordinated pilot tests could be conducted in fewer, targeted reservoirs rather than in all impaired reservoirs. Reservoir owners and operators would convene a third-party independent Technical Review Committee to advise on pilot tests.

Reservoir owners and operators would use lessons learned from pilot tests to develop long-term reservoir and fisheries management plans. In program review after Phase 1, the Technical Review Committee and the State Water Board would evaluate results of pilot tests and long-term reservoir and fisheries management plans.

Potential pilot tests

Manage reservoir water chemistry to reduce methylmercury production:

- Oxidant addition to reservoir bottom waters (near the sediment-water interface) to reduce anoxia or adjust redox potential when reservoirs are stratified to suppress methylation of mercury. Evaluate various oxidants (e.g., dissolved oxygen, ozone, nitrate, others) for (a) efficacy for methylmercury reduction, (b) multiple benefits (e.g., drinking water quality, algal controls), and (c) avoidance of adverse consequences;
- In-reservoir sediment removal or encapsulation to address inorganic mercury hotspots such as submerged or near-shore mine sites and mining waste; and
- Other management practices to reduce methylation, including enhancing demethylation.

Manage fisheries to reduce fish bioaccumulation of methylmercury:

- Nutrient management such as minimal additions of nitrogen or phosphorus (including from natural sources such as restoring historical salmon runs) to slightly increase chlorophyll-a concentrations in oligotrophic reservoirs;
- Intensive fishing to increase the growth rate of remaining fish;
- New or changes to fish stocking practices to increase the abundance of fish with lower methylmercury levels, such as (a) stock low-methylmercury prey fish for reservoir predator fish to consume, (b) stock more or different sport fish species, such as lower trophic level sport fish, and/or (c) stock large, old predator fish from hatcheries that supply low methylmercury fish; and
- Assess potential changes to make to fish assemblage that result in top predator fish with lower methylmercury levels.

Mine sites upstream of reservoirs

The Water Boards would compel, using existing authorities, cleanup of the highest priority mine sites upstream of mercury-impaired reservoirs. Cleanup of highest priority mine sites is expected to reasonably quickly decrease reservoir mercury concentrations.

Exposure reduction

Human health should be protected while pilot tests are underway and inorganic mercury source reductions are occurring. This would involve reservoir owners and operators, the State Department of Public Health, Office of Environmental Health Hazard Assessment, and other stakeholders, for actions such as the following:

- Post fish consumption warning signs;

- Recommend fish catch restrictions to reduce human consumption of larger, older fish with high methylmercury levels, e.g., “slot limits” that specify a safe size range of fish for consumption; and
- Conduct public outreach and educational activities to discourage people from consuming fish with highly elevated methylmercury.

Atmospheric deposition

The California Air Resources Board and USEPA should evaluate atmospheric deposition of mercury to California. California already reduced anthropogenic emissions of mercury by more than half since 2001 and is expected to achieve the load allocation (see “Reservoir Mercury TMDL” section) by the end of Phase 1. The Water Boards would encourage USEPA to increase its efforts to address mercury emissions from foreign countries (particularly artisanal gold mining on several continents and power plant emissions in Asia).

S-6 Other Actions in Phase 1

Urban runoff to Mercury-Impaired Reservoirs (Storm water NPDES Dischargers)

“MS4 permittees” are responsible for urban runoff from municipal separate storm sewer systems (MS4s) regulated by National Pollutant Discharge Elimination System (NPDES) permits. Large MS4 permittees in highly urbanized areas would monitor methylmercury in their discharges upstream of or directly to mercury-impaired reservoirs. In program review after Phase 1, the State Water Board would evaluate these data as a first step toward determining whether methylmercury controls from MS4 permittees are needed.

MS4 permittees located upstream of mercury-impaired reservoirs that contain historical mercury mine sites, or gold or silver mine sites where mercury was used, would ensure that earth-moving projects will employ erosion and sediment control best management practices to prevent discharge of mercury.

Municipal and Industrial Wastewater Facility Discharges to Mercury-Impaired Reservoirs (Non-Stormwater NPDES Dischargers)

The Water Boards would include the following in the next permit cycle for NPDES-permitted municipal and industrial wastewater facilities that discharge upstream of or directly to impaired reservoirs:

- Mercury numeric effluent limitations based on waste load allocations (see “Reservoir Mercury TMDL” section);
- Require dischargers to monitor total mercury in effluent; and
- Require dischargers with treatment pond systems to monitor methylmercury in effluent for up to two years.

In program review after Phase 1, the State Water Board will evaluate these data as a first step toward determining whether methylmercury controls are needed for discharges from treatment pond systems.

Dredging and earth-moving

The Water Boards issue certifications or permits for projects such as dredging in reservoirs and creek channels downstream of mine sites, and earth-moving projects such as construction of roads and watercourse crossings near mines. Future certifications and permits would include requirements for erosion and sediment control best management practices to prevent discharge of mercury.

S-7 Reservoir Mercury Total Maximum Daily Load

This Statewide Mercury Control Program for Reservoirs would establish a total maximum daily load for mercury-impaired reservoirs (Reservoir Mercury TMDL) that would include the following elements.

Numeric targets

Three targets, one set equal to the sport fish objective, one set equal to the CA least tern objective, and one set equal to the prey fish objective. The targets apply to the impaired reservoirs corresponding to the mercury objectives. One or two of these three mercury targets apply to each mercury-impaired reservoir (see Table S-1).

Source assessment

Mercury sources are not evenly distributed across the State and no one source type is responsible for all reservoir impairments. The most important anthropogenic sources to impaired reservoirs are historical mine sites and atmospheric deposition from global and California industrial emissions.

Mercury is naturally-occurring in many geologic formations. Natural background (pre-industrial) concentrations in soils and sediments reflect naturally-occurring mercury from native geologic formations and volcanoes. California's Coast Ranges have some of the world's most productive mercury mines, and much of this mercury was used in gold mines in the Sierra Nevada and elsewhere.

Modern background soil mercury levels are elevated above natural background because mercury emissions and associated atmospheric deposition have increased greatly since the dawn of the industrial era. "Atmospheric deposition" is the term for this source after emissions settle onto the landscape or water surface. National and global emission inventories indicate that California anthropogenic emissions have decreased substantially in recent years while emissions from Asia have increased.

Historical gold, silver, and mercury mining activities were widespread in many of California's watersheds, and most mining activities occurred upstream of reservoirs. Yet, many mercury-impaired reservoirs downstream of mines do not have elevated sediment mercury concentrations.

In contrast to mines upstream of reservoirs, the majority of California's urban areas are downstream of reservoirs. NPDES-permitted urban runoff and treated wastewater facility discharges are generally insignificant sources of mercury.

Linkage analysis

There is a relationship between fish methylmercury concentrations and the environmental factors that control methylmercury production, bioaccumulation, and biomagnification in California reservoirs. More than 70 environmental factors have been assessed using statistical analyses and model development based on data collected from California reservoirs.

The linkage analysis indicates that no single factor explains fish methylmercury concentrations in California reservoirs. Multiple factors drive reservoir fish methylmercury levels: amount of mercury, methylmercury production, and bioaccumulation. The ratio of aqueous methylmercury to chlorophyll-a, aqueous total mercury, and annual reservoir water level fluctuations explain greater than 85% of the variability in reservoir fish methylmercury concentrations.

TMDL and loading capacity

The Reservoir Mercury TMDL and loading capacity for reservoirs is the sum of:

- Inorganic mercury waste load allocations for large and small NPDES-permitted discharges from municipal and industrial facilities;
- Inorganic mercury load allocations for mining waste, soils, and atmospheric deposition; and
- Methylmercury load allocation for in-reservoir methylmercury production.

The load allocations for soils and atmospheric deposition include natural background.

Waste Load Allocations (WLAs) for point sources

Facilities with individual NPDES permits are categorized as large, small, or negligible dischargers based on a comparison of their design flows to reservoir inflows. The WLAs are based on current performance and expressed as concentrations (nanograms of total mercury per liter [ng/L], calendar year average), as follows:

- Large municipal waste water treatment plants (WWTPs): 10 ng/L
- Other large facilities: 30 ng/L
- Small WWTPs: 20 ng/L
- Other small facilities: 60 ng/L

No WLAs are proposed for NPDES-permitted facilities with negligible discharges.

No WLAs are assigned to urban runoff discharged by MS4 entities and stormwater discharged by construction and industrial activities because mercury in these discharges is accounted for in the load allocations for atmospheric deposition.

Load allocations for nonpoint sources

Total mercury load allocations for mining waste and soils are based on mercury regions in California and expressed as concentrations (milligrams of mercury per kilogram of soil [mg/kg, dry weight, annual median]), as follows:

- 0.1 mg/kg for trace mercury areas;
- 0.3 mg/kg for mercury-enriched areas; and
- 400 mg/kg or a site-specific cleanup standard for mercury mineralized zone. (This mercury concentration is characteristic of background levels observed at mercury mine sites in the Coast Ranges.)

The statewide total mercury load allocations for atmospheric deposition are expressed as loads (kilograms of mercury per year [kg/yr]), as follows:

- 1,400 kg/yr for deposition from natural sources;
- 230 kg/yr for deposition from anthropogenic sources within California; and
- 1,600 kg/yr for deposition from anthropogenic sources outside of California.

The load allocation for in-reservoir methylmercury production is no detectable methylmercury in unfiltered reservoir water (calendar year median for the entire water column, including the epilimnion and hypolimnion) with a detection limit of 0.009 ng/L.

Tables

Table S-1. Applicability of Numeric Targets

	Highest Trophic Level in Reservoir (TL4 Fish)	**Highest Trophic Level in Reservoir (TL3 Fish)**
Not habitat for California least tern	sport fish target applies	sport fish and prey fish targets apply
Habitat for California least tern	sport fish and CA least tern targets apply	sport fish and CA least tern targets apply

Table S-2 is provided on the following pages.

Table S-2 List of Mercury-Impaired Reservoirs to be Included in Phase 1

See notes at bottom of table, especially note 2 regarding mercury-impaired reservoirs with Federal Energy Regulatory Commission (FERC) hydropower licenses.

Reservoir	**Water Board Region**	**County(ies)**	**Owner**	**Operator** (if different from owner)	**303(d) List**	**FERC License No.**	**FERC Expiration Date**	**FERC with CWA 401 Certification**
Almanor, Lake	5	Plumas	Pacific Gas and Electric Co.		2010	FERC 2105	10/31/2004	
Alondra Park Lake	4	Los Angeles	Los Angeles Co. Dept of Parks and Recreation		Future			
Amador, Lake	5	Amador	Jackson Valley ID		Future	FERC5388	FERC Exempt	
Anderson Lake	2	Santa Clara	Santa Clara Valley Water District		2010			
Arrowhead, Lake	6	San Bernardino	Arrowhead Lake Association		2012			
Bass Lake	5	Madera	Pacific Gas and Electric Co.		Future	FERC1354	8/31/2043	
Beach Lake	5	Sacramento	Sacramento Regional County Sanitation District		2010			
Berryessa, Lake	5	Napa, Yolo	U.S. Bureau of Reclamation	Solano County Water Agency	2010	FERC 2780	12/31/2030	
Big Bear Lake	8	San Bernardino	Big Bear Municipal Water District		2010			
Black Butte Lake	5	Glenn, Tehama	U.S. Army Corps of Engineers	Santa Clara, City of	2010	FERC 3190	4/30/2033	
BLM Reservoir/Buena Vista Mine	3	San Luis Obispo	U.S. Bureau of Land Management		Future			
Bon Tempe Lake	2	Marin	Marin Municipal Water District		2010			
Bowman Lake	5	Nevada	Nevada Irrigation District		Future	FERC 2266	4/30/2013	
Briones Reservoir	2	Contra Costa	East Bay Municipal Utility District		Future			

***Table S-2** continued*

Reservoir	Water Board Region	County(ies)	Owner	Operator (if different from owner)	303(d) List	FERC License No.	FERC Expiration Date	FERC with CWA 401 Certification
Brite Valley Lake	5	Kern	Tehachapi-Cummings Co WD		Future			
Britton, Lake	5	Shasta	Pacific Gas and Electric Co.		2010	FERC 233	6/30/2043	1/25/2007
Butt Valley Reservoir	5	Plumas	Pacific Gas and Electric Co.		Future	FERC 2105	10/31/2004	
Cachuma, Lake	3	Santa Barbara	U.S. Bureau of Reclamation		Future			
Calaveras Reservoir	2	Alameda, Santa Clara	San Francisco, City & Co. of		2010			
California, Lake	5	Tehama	Lake California Property Owners Association		Future			
Camanche Reservoir	5	Amador, Calaveras, San Joaquin	East Bay Municipal Utility District		2010	FERC 2916	3/31/2031	
Camden Percolation Pond	2	Santa Clara	Santa Clara Valley Water District		Future			
Camp Far West Reservoir	5	Nevada, Placer, Yuba	South Sutter Water District		2010	FERC 2997	6/30/2021	
Casitas, Lake	4	Ventura	U.S. Bureau of Reclamation	Casitas Municipal Water District	2010			
Castac Lake	5	Kern	Tejon Ranch Co		Future			
Castaic Lagoon	4	Los Angeles	Los Angeles County Department of Parks and Recreation		Future			
Castaic Lake	4	Los Angeles	CA Department of Water Resources		2010			
Cave Lake	5	Modoc	U.S. Forest Service		Future			

***Table S-2** continued*

Reservoir	Water Board Region	County(ies)	Owner	Operator (if different from owner)	303(d) List	FERC License No.	FERC Expiration Date	FERC with CWA 401 Certification
Cerritos Park Lake	4	Los Angeles	Los Angeles County Department of Parks and Recreation		Future			
Chabot, Lake (Alameda Co.)	2	Alameda	East Bay Municipal Utility District		2010			
Chabot, Lake (Solano Co.)	2	Solano	Vallejo, City of		Future			
Chesbro Reservoir	3	Santa Clara	Santa Clara Valley Water District		2010			
Collins Lake	5	Yuba	Browns Valley ID		Future			
Combie, Lake	5	Nevada, Placer	Nevada Irrigation District		2010	FERC 2981	Exempt	
Contra Loma Reservoir	5	Contra Costa	U.S. Bureau of Reclamation		Future			
Copco Lake	1	Siskiyou	Pacific Power and Light Co.		2012	FERC 2082	3/1/2006	
Coyote Lake	2	Santa Clara	Santa Clara Valley Water District		Future			
Crowley Lake	6	Mono	Los Angeles, City of		Future			
Davis Creek Reservoir	5	Yolo	Homestake Mining Co.		2010			
Dead Lake	1	Del Norte	CA Department of Parks and Recreation		2012			
Del Valle Reservoir	2	Alameda	CA Department of Water Resources		2010			
Don Pedro Lake	5	Tuolumne	Turlock & Modesto Irrigation District		2010	FERC 2299	4/30/2016	
Donner Lake	6	Nevada	Truckee Meadows Water Authority		Future			

***Table S-2** continued*

Reservoir	Water Board Region	County(ies)	Owner	Operator (if different from owner)	303(d) List	FERC License No.	FERC Expiration Date	FERC with CWA 401 Certification
East Park Reservoir	5	Colusa	U.S. Bureau of Reclamation	Orland Unit Water Users` Association	2010			
El Capitan Reservoir	9	San Diego	San Diego, City of		Future			
El Dorado Park Lakes	4	Los Angeles	Long Beach, City of		2010			
Elderberry Forebay	4	Los Angeles	Los Angeles, City of		Future	FERC 2426	1/31/2022	
Englebright Lake	5	Nevada, Yuba	U.S. Army Corps of Engineers	Yuba County Water Agency/Pacific Gas and Electric Company	2010	FERC 2246, 1403	03/31/2016, 01/31/2023	
Fallen Leaf Lake	6	El Dorado	U.S. Forest Service		Future			
Faucherie Lake	5	Nevada	Nevada Irrigation District		Future	FERC 2266	4/30/2013	
Finger Lake	5	Tehama	Endicott Bert		Future			
Folsom Lake	5	El Dorado, Placer, Sacramento	U.S. Bureau of Reclamation		2010			
French Meadows Reservoir	5	Placer	Placer Co. Water Agency		Future	FERC 2079	2/28/2013	
Frenchman Lake	5	Plumas	California Water Resources Dept		Future			
Grass Valley Lake	6	San Bernardino	Arrowhead Lake Association		Future			
Gregory, Lake	6	San Bernardino	San Bernardino, County of. Reg Parks		2012			
Hansen Dam Lake	4	Los Angeles	U.S. Army Corps of Engineers		Future			
Hell Hole Reservoir	5	Placer	Placer County Water Agency		2010	FERC 2079	2/28/2013	

***Table S-2** continued*

Reservoir	Water Board Region	County(ies)	Owner	Operator (if different from owner)	303(d) List	FERC License No.	FERC Expiration Date	FERC with CWA 401 Certification
Henne, Lake	2	Napa	Howell Mtn Mutual Water Co		Future			
Henshaw, Lake	9	San Diego	Vista Irrigation District/ City of Escandido		Future	FERC176	FERC Exempt	
Hensley Lake	5	Madera	U.S. Army Corps of Engineers		2010			
Herman, Lake	2	Solano	Benicia, City of		2010			
Hernandez Reservoir	3	San Benito	Can Benito County Water District		1998			
Hetch Hetchy Reservoir	5	Tuolumne	San Francisco, City & Co. of	San Francisco Public Utilities Commission	2010			
Hodges, Lake	9	San Diego	San Diego, City of		2010			
Hughes, Lake	4	Los Angeles	U.S. Forest Service		Future			
Indian Creek Reservoir	6	Alpine	So Tahoe Public Utility Dist		Future			
Indian Valley Reservoir	5	Lake	Yolo County Flood Control & Water Conservation District		2010			
Iron Gate Reservoir	1	Siskiyou	Pacific Power and Light Co.		2012	FERC 2082	3/1/2006	
Irvine Lake	8	Orange	Serrano Wd & Irvine Ranch WD		Future			
Isabella Lake	5	Kern	U.S. Army Corps of Engineers	Isabella Partners	Future	FERC8377	5/31/2038	
Jackson Meadow Reservoir	5	Nevada, Sierra	Nevada Irrigation District		Future	FERC 2266	4/30/2013	
Jameson Lake	3	Santa Barbara	Montecito Water District		Future			

***Table S-2** continued*

Reservoir	Water Board Region	County(ies)	Owner	Operator (if different from owner)	303(d) List	FERC License No.	FERC Expiration Date	FERC with CWA 401 Certification
Jenkinson Lake	5	El Dorado	El Dorado ID		Future			
Jennings, Lake	9	San Diego	Helix WD		Future			
Kaweah, Lake	5	Tulare	U.S. Army Corps of Engineers	Kaweah River and Power Authority	2010	FERC 3947	7/31/2036	
Ken Hahn Park Lake	4	Los Angeles	California Dept. of Parks and Rec.		Future			
La Mirada Park Lake	4	Los Angeles	Los Angeles Co. Dept of Parks and Recreation		Future			
Lafayette Reservoir	2	Contra Costa	East Bay Municipal Utility District		2010			
Lee Lake/Corona Lake	8	Riverside	Elsinore Valley MWD		Future			
Legg Lake	4	Los Angeles	Los Angeles Co. Dept of Parks and Recreation		Future			
Lexington Reservoir	2	Santa Clara	Santa Clara Valley Water District		Future			
Little Rock Reservoir	6	Los Angeles	Little Rock Creek ID		2012			
Loch Lomond Reservoir	3	Santa Cruz	Santa Cruz, City of		Future			
Loon Lake	5	El Dorado	Sacramento Municipal Utility District		Future	FERC 2101	6/30/2064	10/4/2013
Lopez Lake	3	San Luis Obispo	San Luis Obispo Co FCWCD		Future			
Los Banos Reservoir	5	Merced	U.S. Bureau of Reclamation		Future			
Los Vaqueros Reservoir	5	Contra Costa	Contra Costa Co WD		Future			

***Table S-2** continued*

Reservoir	Water Board Region	County(ies)	Owner	Operator (if different from owner)	303(d) List	FERC License No.	FERC Expiration Date	FERC with CWA 401 Certification
Loveland Res	9	San Diego	Sweetwater Authority, South Bay ID		Future			
Lower Crystal Springs Reservoir	2	San Mateo	San Francisco, City & Co. of		Future			
Lower Otay Reservoir	9	San Diego	San Diego, City of		Future			
Malibou Lake	4	Los Angeles	Malibu Lake Mtn Club Inc		Future			
Mammoth Pool Reservoir	5	Fresno, Madera	Southern California Edison Co.		Future	FERC2085	11/30/2007	
Marsh Creek Reservoir	5	Contra Costa	Contra Costa County Flood Control & Water Conservation District		2010			
Marsh in Fresno Slough	5	Fresno	Fresno Slough WD		Future			
Mathews, Lake	8	Riverside	Metropolitan WD of Southern California		Future			
McClure, Lake	5	Mariposa	Merced Irrigation District		2010	FERC 2179	2/28/2014	
McSwain, Lake	5	Mariposa	Merced Irrigation District		Future	FERC 2179	2/28/2014	
Mendocino, Lake	1	Mendocino	U.S. Army Corps of Engineers	Sonoma County Water Agency	2010	FERC 2841	3/31/2032	
Mile Long Pond	5	Butte	CA Department of Water Resources		2010			
Millerton Lake	5	Fresno, Madera	U.S. Bureau of Reclamation	Friant Power Authority	2010	FERC 2892	8/31/2032	
Modesto Reservoir	5	Stanislaus	Modesto Irrigation District		2010			

***Table S-2** continued*

Reservoir	Water Board Region	County(ies)	Owner	Operator (if different from owner)	303(d) List	FERC License No.	FERC Expiration Date	FERC with CWA 401 Certification
Moon Lake	5	Lassen	John Hancock Mutual Ins Co		Future			
Morena Reservoir	9	San Diego	San Diego, City of		Future			
Nacimiento, Lake	3	San Luis Obispo	Monterey County Water Resources Agency		2010	FERC6378	FERC Exempt	
Natoma, Lake	5	Sacramento	U.S. Bureau of Reclamation		2010			
New Bullards Bar Reservoir	5	Yuba	Yuba County Water Agency		2010	FERC 2246	3/31/2016	
New Hogan Lake	5	Calaveras	U.S. Army Corps of Engineers	Modesto Irrigation District	2010	FERC 2903	10/31/2032	
New Melones Lake	5	Calaveras, Tuolumne	U.S. Bureau of Reclamation		2010			
Nicasio Reservoir	2	Marin	Marin Municipal Water District		2010			
Ogier Quarry Ponds	2	Santa Clara	Santa Clara, County of		Future			
O'Neill Forebay	5	Merced	U.S. Bureau of Reclamation	CA Department of Water Resources	2010			
Oroville, Lake	5	Butte	CA Department of Water Resources		2010	FERC 2100	1/31/2007	8/31/2010
Oxbow Reservoir	5	El Dorado, Placer	Placer County Water Agency		2010	FERC 2079	2/28/2013	
Palmdale Lake	6	Los Angeles	Palmdale Water District		Future			
Paradise Lake	5	Butte	Paradise Irrigation District		Future			
Pardee Reservoir	5	Amador, Calaveras	East Bay Municipal Utility District		2010	FERC 2916	3/31/2031	

***Table S-2** continued*

Reservoir	Water Board Region	County(ies)	Owner	Operator (if different from owner)	303(d) List	FERC License No.	FERC Expiration Date	FERC with CWA 401 Certification
Peck Road Park Lake	4	Los Angeles	Los Angeles Co. Dept of Parks and Recreation		Future			
Perris Reservoir	8	Riverside	California Water Resources Dept		Future			
Pilarcitos Lake	2	San Mateo	San Francisco, City & Co. of		Future			
Pillsbury, Lake	1	Lake	Pacific Gas and Electric Co.		2010	FERC 77	4/14/2022	
Pine Flat Lake	5	Fresno	U.S. Army Corps of Engineers	Pacific Gas and Electric Company and Kings River Conservation District	2010	FERC 175, 1988, 2741	08/31/2029, 04/30/2026, 02/28/2041	
Pinto Lake	3	Santa Cruz	Santa Cruz, County of. Dept. of Public Works		Future			
Piru, Lake	4	Ventura	United Water Control District		Future	FERC2153	8/31/2048	
Puddingstone Reservoir	4	Los Angeles	Los Angeles County Department of Public Works		2010			
Pyramid Lake	4	Los Angeles	CA Department of Water Resources		2010	FERC 2426	1/31/2022	
Robinson's Pond	5	Butte	CA Department of Fish and Wildlife		2010			
Rollins Reservoir	5	Nevada, Placer	Nevada Irrigation District		2010	FERC 2266	4/30/2013	
Ruth Lake	1	Trinity	Humboldt Bay MWD	Humboldt Bay Municipal Water District	2012	FERC 1993	FERC Exempt	
San Antonio Reservoir	3	Monterey, San Luis Obispo	Monterey County Water Resources Agency		2010			
San Luis Reservoir	5	Merced	U.S. Bureau of Reclamation	CA Department of Water Resources	2010			

Table S-2 *continued*

Reservoir	Water Board Region	County(ies)	Owner	Operator (if different from owner)	303(d) List	FERC License No.	FERC Expiration Date	FERC with CWA 401 Certification
San Pablo Reservoir	2	Contra Costa	East Bay Municipal Utility District		2010			
San Vicente Reservoir	9	San Diego	San Diego, City of		Future	FERC14642		
Santa Fe Dam Park Lake	4	Los Angeles	U.S. Army Corps of Engineers		Future			
Santa Margarita Lake	3	San Luis Obispo	U.S. Army Corps of Engineers		Future			
Scotts Flat Reservoir	5	Nevada	Nevada Irrigation District		2010			
Shadow Cliffs Reservoir	2	Alameda	East Bay Regional Park District		2010			
Shasta Lake	5	Shasta	U.S. Bureau of Reclamation		2010			
Shastina, Lake	1	Siskiyou	Montague Water Conservation District		2010			
Sherwood, Lake	4	Ventura	Westlake Lake Management Association		2010			
Silverwood Lake	6	San Bernardino	California Water Resources Dept		2012	FERC14797	1/31/2022	
Siskiyou Lake	5	Siskiyou	Siskiyou Co. FCWCD		Future			
Slab Creek Reservoir	5	El Dorado	Sacramento Municipal Utility District		2010	FERC 2101	6/30/2064	7/12/2016
Solano, Lake	5	Yolo	U.S. Bureau of Reclamation	Solano County Water Agency	2010	FERC 2780	12/31/2030	
Sonoma, Lake	1	Sonoma	U.S. Army Corps of Engineers		2010	FERC 3351	11/30/2034	
Spicer Meadow Reservoir	5	Tuolumne, Alpine	Calaveras Co. WD	Northern California Power Authority	Future	FERC 2409	1/31/2032	

***Table S-2** continued*

Reservoir	Water Board Region	County(ies)	Owner	Operator (if different from owner)	303(d) List	FERC License No.	FERC Expiration Date	FERC with CWA 401 Certification
Spring Lake	1	Sonoma	Sonoma Co. Water Agency		Future			
Stevens Creek Reservoir	2	Santa Clara	Santa Clara Valley Water District		2010			
Stony Gorge Reservoir	5	Glenn	U.S. Bureau of Reclamation	Orland Unit Water Users` Association	2010	FERC 3193	7/31/2032	
Sutherland, Lake	9	San Diego	San Diego, City of		Future			
Sweetwater Reservoir	9	San Diego	Sweetwater Authority		Future			
Thermalito Afterbay	5	Butte	CA Department of Water Resources		2010	FERC 2100	1/31/2007	12/15/2010
Topaz Lake	6	Mono	Walker River Irrigation District		2012			
Trinity Lake	1	Trinity	U.S. Bureau of Reclamation		2010			
Tulloch Reservoir	5	Calaveras, Tuolumne	South San Joaquin and Oakdale Irrigation Districts		2010	FERC 2067	12/31/2046	9/15/2005
Tunnel Reservoir	5	Shasta	Pacific Gas and Electric Co.		Future	FERC 233	6/30/2043	
Turlock Lake	5	Stanislaus	Turlock Irrigation District		2010			
Upper San Leandro Reservoir	2	Alameda, Contra Costa	East Bay Municipal Utility District		Future			
Upper Twin Lake	6	Mono	Centennial Livestock		2012			
Uvas Reservoir	3	Santa Clara	Santa Clara Valley Water District		2010			
Vasona Reservoir	2	Santa Clara	Santa Clara Valley Water District		Future			

***Table S-2** continued*

Reservoir	Water Board Region	County(ies)	Owner	Operator (if different from owner)	303(d) List	FERC License No.	FERC Expiration Date	FERC with CWA 401 Certification
Webb, Lake	5	Kern	Kern Co Dept of Parks & Rec		Future			
West Valley Reservoir	5	Modoc, Lassen	South Fork Irrigation District		Future			
Westlake Lake	4	Los Angeles, Ventura	Westlake Lake Management Association		Future			
Whiskeytown Lake	5	Shasta	U.S. Bureau of Reclamation		2010			
Wildwood, Lake	5	Nevada	Lake Wildwood Association		2010			
Woodward Reservoir	5	Stanislaus	South San Joaquin Irrigation District		2010			
Zayak/Swan Lake	5	Nevada	Lakewood Association		Future			

Notes

1 FERC: Federal Energy Regulatory Commission hydropower license

2 Table S-1 lists the mercury-impaired reservoirs that would be included in Phase 1 and mercury-impaired reservoirs with FERC licenses that would be addressed in the future. In Phase 2, requirements would be applied to additional reservoirs and corresponding mercury sources as the reservoirs are determined to be mercury-impaired by the Water Boards.

3 303(d) List: “1998,” “2010,” or “2012” indicates the year that reservoirs impaired by mercury were included on the Clean Water Act section 303(d) List. These lists are available at: http://www.waterboards.ca.gov/water_issues/programs/water_quality_assessment/#impaired

4 “Future” indicates that fish have elevated methylmercury levels; data analysis is planned to be reported in a future staff report for public review.

5 "FERC with CWA 401 Certification with Mercury Re-opener" indicates that the previous FERC license renewal included in the Clean Water Act section 401 Water Quality Certification a provision to re-open the 401 certification for water quality reasons including mercury.

1 INTRODUCTION

Harmful levels of methylmercury in fish are a statewide and nationwide problem. More than 180 freshwater bodies in California are designated as impaired by mercury by the U.S. Environmental Protection Agency (USEPA), and more than 70 of these are reservoirs.

Mercury is a bioaccumulative toxic pollutant that results in many reservoir fish having methylmercury levels that pose a risk for humans and wildlife that eat the fish. Mercury does not impair drinking water quality in California reservoirs. The number of reservoirs determined to be impaired by mercury is expected to increase substantially as new fish tissue monitoring data are collected and evaluated.

To address the mercury problem in reservoirs, the State Water Resources Control Board (State Water Board) has undertaken a statewide program ("Statewide Mercury Control Program for Reservoirs"), which has the following main goals:

1. Reduce fish methylmercury concentrations in reservoirs that have already been determined to be mercury-impaired;
2. Have a control program in place that will apply to additional reservoirs when they are determined in the future to be mercury-impaired;
3. Protect additional reservoirs from becoming mercury-impaired.

To achieve these goals, the State Water Board is proposing to establish a rule, as described in the next section.

Rule: Mercury Reservoir Provisions

The State Water Board is proposing to establish a rule titled, "Amendment to the Water Quality Control Plan for Inland Surface Waters, Enclosed Bays, and Estuaries of California—Mercury TMDL and Implementation Program for Reservoirs" (hereinafter, Mercury Reservoir Provisions) to address the problem of mercury in reservoirs.

Scientific Peer Review

Health and Safety Code section 57004 requires all departments and boards within California Environmental Protection Agency to submit for external scientific peer review the scientific basis and scientific portion of proposed rules. This staff report contains the scientific basis and the scientific portions of the Mercury Reservoir Provisions. Also submitted for scientific peer review, although not part of Mercury Reservoir Provisions, is a weight-of-evidence method that can be considered for assessing attainment with mercury water quality objectives (described in Chapter 10, Appendix L).

Portions of the text in this staff report are in italicized font and indented to denote elements of the staff report that will be developed subsequent to scientific peer review. Such elements are not necessary to aid the peer reviewer's evaluation of the scientific basis and the scientific portion of the Mercury Reservoir Provisions.

1.1 Proposed Mercury Reservoir Provisions

The Mercury Reservoir Provisions implements water quality objectives being established for the reasonable protection of beneficial uses for commercial and sport fishing (COMM), wildlife habitat (WILD), and preservation of rare and endangered species (RARE) (see section 1.4). The provisions focus on reservoirs in the state to efficiently address the continuing health risks due to consumption of fish from many reservoirs by humans and wildlife.

The Mercury Reservoir Provisions include several key elements. The first element is a program of implementation for achieving and maintaining mercury water quality objectives (see below) in reservoirs. The program of implementation includes control actions for (1) point and nonpoint sources of mercury, and pilot tests for (2) reservoir water chemistry to reduce methylmercury production, and (3) fisheries management to reduce methylmercury bioaccumulation. The second element consists of recommendations (1) to protect people who eat mercury-contaminated reservoir fish while pilot tests are underway and inorganic mercury source reductions are occurring, (2) directed to the California Department of Fish and Wildlife for fisheries management, and (3) directed to other agencies to ensure reductions in atmospheric mercury. The third element is a “total maximum daily load” for mercury-impaired reservoirs (Reservoir Mercury TMDL). (Section 1.5.2 explains that the Reservoir Mercury TMDL applies to all mercury-impaired reservoirs, which includes both those on the Clean Water Act section 303(d) List and other reservoirs the State Water Board determines to be impaired by mercury.)

This Statewide Mercury Control Program for Reservoirs would implement three mercury water quality objectives concurrently being developed by a separate State Water Board project, described in the following section.

Separate project: Mercury Objectives Provisions

Concurrent with the development of the Mercury Reservoir Provisions, the State Water Board is developing a separate project titled, “Part 2 of the Water Quality Control Plan for Inland Surface Waters, Enclosed Bays, and Estuaries of California—Tribal and Subsistence Fishing Beneficial Uses and Mercury Provisions” (hereinafter, Mercury Objectives Provisions). The Mercury Objectives Provisions would establish three new beneficial uses, five water quality objectives, and a program of implementation to protect beneficial uses associated with COMM, WILD, RARE, Tribal Subsistence Fishing (T-SUB), and Subsistence Fishing (SUB) applicable to surface waters in the state. Although both projects are being developed to control mercury, only the Mercury Objectives Provisions would establish numeric water quality objectives. The draft Mercury Objectives Provisions and its accompanying draft staff report is located here: [*link*].

The Mercury Reservoir Provisions is a separate and independent implementation program to control mercury at reservoirs by implementing three of the water quality objectives being developed by the Mercury Objectives Provisions (the Sport Fish Water Quality Objective, the Prey Fish Water Quality Objective, and the California Least Tern Prey Fish Water Quality Objective) to protect the COMM, WILD, and RARE beneficial uses at reservoirs. While both projects are being developed concurrently, the Mercury Reservoir Provisions would not be proposed for adoption by the State Water Board until after the Board adopts, and Office of Administrative Law approves, the Mercury Objectives Provisions.

1.2 Report Organization

This staff report contains the scientific portion and scientific basis for the Mercury Reservoir Provisions. After scientific peer review, this staff report will be one of several documents distributed to public agencies and members of the public for review and comment. Page viii of this staff report provides a description of the anticipated documents. More information and links to available documents are provided on the State Water Board's website here: [*link*].

This staff report is organized into the following chapters. Chapters 1 through 3 explain the mercury problem and provide background information. Specifically, Chapter 1 (Introduction) describes the mercury problem in California's reservoirs and definition of reservoir. Chapter 2 (Numeric Targets) provides the desired fish methylmercury levels in reservoirs to protect COMM, WILD, and RARE beneficial uses of water for human and wildlife consumption of fish. Chapter 3 (Reservoir and Watershed Characteristics) describes California reservoir fish methylmercury levels and watershed characteristics.

Chapters 4 through 7 provide the scientific basis for the Mercury Reservoir Provisions. Specifically, Chapter 4 (Conceptual Model: The Mercury Cycle and Bioaccumulation) describes the conceptual model of mercury cycling within California's reservoirs. Chapter 5 (Linkage Analysis) describes the mathematical relationship between many factors that contribute to the mercury problem and the numeric targets for fish methylmercury concentrations. Chapter 6 (Source Assessment) identifies watershed and atmospheric sources of natural and anthropogenic mercury. Chapter 7 (Assessment of Allocation and Implementation Options) identifies potentially controllable processes and provides initial projections for reducing fish methylmercury levels based on predictions for source reductions together with conclusions of the conceptual model, linkage, and source assessment chapters. Included at the beginning of Chapters 4–7 are expanded overviews that:

- Identify the chapter goals;
- Briefly summarize select material from previous chapter(s) that direct the goals for the chapter;
- Summarize key conclusions; and
- Describe the implications of the conclusions.

The results of the scientific analyses in Chapters 4 through 7 guide the development of the load and waste load allocations and the program of implementation (Chapters 8, 9, and 10), which are key components of an effective rule.

Chapter 8 (Allocations, TMDL, and Loading Capacity) proposes reservoir mercury loading capacity, a corresponding TMDL, and allocations for mercury sources. Chapter 9 (Implementation Plan) proposes actions for (1) point and nonpoint sources of mercury, (2) reservoir water chemistry management activities that affect methylmercury production, and (3) fisheries management activities that affect methylmercury bioaccumulation. The actions proposed in Chapter 9 are necessary to achieve the mercury water quality objectives and TMDL targets in reservoirs. The adaptive implementation section in Chapter 9 describes how the State Water Board will consider information obtained after the adoption of the Mercury Reservoir

Provisions. Chapter 10 (Mercury and Methylmercury Monitoring and Pilot Test Guidance) describes monitoring to evaluate progress towards attaining the targets.

Lastly, Chapter 11 (References) and the Appendices include information relied upon to prepare this staff report. Chapter 11 lists information sources cited.

Appendix A describes the importance of primary and secondary production in controlling fish tissue methylmercury concentrations. Appendix Z presents data used for analyses in this staff report. Appendices B through L include supporting analyses.

1.3 Mercury Problem: Elevated Fish Methylmercury Levels

Mercury is a persistent and bioaccumulative toxic pollutant. In humans, the principal route for mercury exposure is through the consumption of mercury-containing fish (USEPA 2001a). Consequently, fish consumption advisories have been issued for many California waters, including a statewide advisory for the state's reservoirs.[1] Reservoir fish methylmercury levels are described in detail in Chapter 3, and mercury-impaired reservoirs are listed in section 1.6.

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 are similar to humans in that fish consumption is the principal route for mercury exposure. Birds and mammals most likely at risk for mercury toxicity are primarily or exclusively piscivorous. Wildlife species that consume fish from California's reservoirs include a wide variety of piscivorous birds, such as herons, egrets, terns, grebes, bald eagle, kingfisher, and osprey; piscivorous fish; and mammals, such as mink, raccoon, and river otter. 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 (Huber 1997), mink (Dansereau et al. 1999), and fish (Huber 1997; Wiener and Spry 1996).

Methylmercury is typically analyzed as "total mercury" fish because of the higher cost for methylmercury analysis and because mercury exists almost entirely in the methylated form in fish (Becker and Bigham 1995; Bloom 1992; Nichols et al. 1999; Slotton et al. 2004; Sveinsdottir and Mason 2005; Wiener et al. 2003). Therefore, even though the fish mercury data presented

[1] Fish consumption advisories are issued by the Office of Environmental Health Hazard Assessment and are available at their website: http://www.oehha.ca.gov/fish.html

in this report were generated by laboratory analyses for total mercury, the data are described as "methylmercury concentrations in fish."

For more information about mercury chemistry and bioaccumulation, please refer to Chapter 4. For more information on mercury toxicity, refer to the Staff Report for the Amendment to the Water Quality Control Plan for Inland Surface Waters, Enclosed Bays, and Estuaries of California—Mercury Water Quality Objectives and Program of Implementation ("Staff Report for Statewide Mercury Water Quality Objectives"). For more information on the beneficial uses impaired in reservoirs, refer to section 1.4 of this staff report.

1.3.1 Which Reservoirs?

Numerous reservoirs throughout California have elevated fish methylmercury levels. The following two sections (1.4 and 1.5) provide concepts used to determine how the Statewide Mercury Control Program for Reservoirs applies to any particular reservoir. The concepts include water quality standards, definition of reservoir, and mercury impairment categories. Section 1.6 describes the Reservoir Mercury Provision's applicability to particular reservoirs.

1.4 Applicable Water Quality Standards

In California, water quality standards include beneficial uses, water quality objectives (narrative or numeric), and antidegradation policy. The Porter-Cologne Water Quality Control Act establishes a comprehensive statutory program for the protection of beneficial uses of the waters of the state. California Water Code section 13050, subdivision (f), describes the beneficial uses of surface and ground waters that may be designated by the State or Regional Boards for protection as follows:

> "Beneficial uses" of the waters of the state that may be protected against quality degradation include, but are not limited to, domestic, municipal, agricultural and industrial supply; power generation; recreation; aesthetic enjoyment; navigation; and preservation and enhancement of fish, wildlife, and other aquatic resources or preserves.

The State Water Board and nine Regional Water Quality Control Boards (collectively, "Water Boards") adopt water quality control plans, which include designated beneficial uses for surface waters and groundwater, establish narrative and numeric objectives to protect those uses, conform with the antidegradation policy, and provide programs of implementation to achieve water quality objectives. The water quality standards applicable to the Statewide Mercury Control Program for Reservoirs are discussed as follows: section 1.4.1 contains the applicable beneficial uses; section 1.4.2 describes the applicable numeric and narrative water quality objectives; Chapters 2 and 8 describe the antidegradation policy; and the program of implementation is described in Chapters 8, 9, and 10.

1.4.1 Reservoir Beneficial Uses

The Clean Water Act and the Porter-Cologne Water Quality Control Act require the identification and protection of beneficial uses. The beneficial uses of California reservoirs include but are not limited to:

- Agricultural Supply (AGR)
- Cold Freshwater Habitat (COLD)
- Commercial and Sport Fishing (COMM)
- Fish Migration (MIGR)
- Fish Spawning (SPWN)
- Freshwater Replenishment (FRSH)
- Groundwater Recharge (GWR)
- Industry – Power, Process, and Service Supply (POW, PROC, IND)
- Municipal and Domestic Supply (MUN)
- Preservation of Rare and Endangered Species (RARE)
- Water Contact Recreation (REC-1)
- Noncontact Water Recreation (REC-2)
- Warm Freshwater Habitat (WARM)
- Wildlife Habitat (WILD)

Of the many beneficial uses of reservoirs, only human and wildlife consumption of fish are impaired by mercury. (The level of mercury in reservoir water does not impair the water for drinking.) The beneficial uses at reservoirs impaired by mercury may include the following:[2]

> **Commercial and Sport Fishing (COMM).** Includes the uses of water for commercial or recreational collection of fish, shellfish, or other organisms including, but not limited to, uses involving organisms intended for human consumption or bait purposes.
>
> **Wildlife Habitat (WILD)**. Includes uses of water that support terrestrial ecosystems including, but not limited to, preservation and enhancement of terrestrial habitats, vegetation, wildlife (e.g., mammals, birds, reptiles, amphibians, invertebrates), or wildlife water and food sources.
>
> **Rare, Threatened, or Endangered Species (RARE)**. Includes uses of water that support habitats necessary, at least in part, for the survival and successful maintenance of plant or animal species established under state or federal law as rare, threatened, or endangered.

Many reservoirs are not designated for the COMM beneficial use. As described in section 1.7, the Mercury Reservoir Provisions would formally designate the COMM beneficial use for the impaired reservoirs identified in Table 1.1.

1.4.2 Overview of the Mercury Water Quality Objectives

This section provides a very brief overview of the three statewide mercury water quality objectives (see Chapter 2 for details). One or two (and not all three) of these objectives applies

[2] Regional Water Boards' Basin Plans may contain slightly different terms within their respective definitions for COMM, WILD, or RARE.

to each reservoir. Two objectives are described by the size of the fish used to measure mercury concentrations, and are called the sport fish water quality objective and prey fish water quality objective. The third objective is described by the bird species it protects, and is called the California least tern water quality objective. Sport fish are much larger than prey fish, and in turn prey fish are a bit larger than the fish consumed by the California least tern. All three objectives are for mercury concentrations in fish averaged over no longer than a calendar year.

1.4.3 Assessment of Water Quality Objectives

Clean Water Act section 303(d) requires states to identify waters (impaired waters) within its boundaries that do not meet or are not expected to meet applicable water quality standards with technology-based controls alone). States are required to include a priority ranking of such waters, taking into account the severity of the pollution and the uses to be made of such waters, including waters targeted for the development of total maximum daily loads (TMDLs). The State Water Board's *Water Quality Control Policy for Developing California's Clean Water Act Section 303(d) List* (hereinafter Listing Policy) describes the process and methods by which the Water Boards add or remove a water body beneficial use and pollutant combination from the Clean Water Act section 303(d) List. In other words, the Listing Policy prescribes the methods for determining whether waters are impaired (and placed on the 303(d) List) or supported.

In addition to the impaired water body list required by Clean Water Act section 303(d), Clean Water Act section 305(b) requires states to report to USEPA on the overall surface water quality, not just those that are impaired. The State Water Board reports on both of these requirements in its "California Integrated Report."[3]

In California, the California Integrated Report uses five categories to classify water quality standards attainment, whereas the Mercury Reservoir Provisions use three categories: impaired, non-assessed, and non-impaired. These categories correspond as follows:

Impaired waters

The 303(d) List is made up of three of the Integrated Report categories, 4a, 4b, and 5 (at least one beneficial use is impaired for a pollutant that still requires the development of a TMDL, is being addressed by a USEPA approved TMDL, or a USEPA approved action other than a TMDL).

Non-assessed waters

Integrated Report category 3 is for waters where there is insufficient information to make a beneficial use support determination.

[3] For example, the 2010 Integrated Report is available at: http://www.waterboards.ca.gov/water_issues/programs/tmdl/integrated2010.shtml

Non-impaired waters

Integrated Report categories 1 and 2 are for waters in which all uses are not impaired or threatened, or information indicates that some, but not all uses, are supported.

Chapter 3 of the Listing Policy provides the listing factors to add a water body to the 303(d) List. For fish mercury or methylmercury data, the applicable listing factor to evaluate whether consumption of fish is impaired is section 3.5 of the Listing Policy, Bioaccumulation of Pollutants in Aquatic Life Tissue. When application of this factor does not result in a listing determination but information indicates that water quality for mercury or methylmercury in fish tissue is suspected to be impaired, then the water segment should be evaluated using section 3.11, the Situation-Specific Weight of Evidence Listing Factor. (The other Listing Factors are not applicable to fish mercury data.) Weight of evidence listing decisions must be justified with a scientifically defensible and reproducible approach. The weight of evidence approach proposed to be used for assessing reservoir fish methylmercury data is in accordance with the Listing Policy and is provided in Chapter 10, Appendix L.

Chapter 4 of the Listing Policy provides the delisting factors to add a water body to the 303(d) List For fish mercury or methylmercury data, the applicable listing factor to evaluate whether consumption of fish is impaired is section 4.5, Bioaccumulation of Pollutants in Aquatic Life Tissue. When application of this factor does not result in a delisting determination but information indicates that water quality for mercury or methylmercury in fish tissue is suspected to be impaired, then the water segment should be evaluated using section 4.11, Situation-Specific Weight of Evidence Listing Factor. (The other delisting factors are not applicable to fish mercury or methylmercury data.) Weight of evidence delisting decisions must be justified with a scientifically defensible and reproducible approach. The weight of evidence approach proposed to be used for assessing reservoir fish methylmercury data is in accordance with the Listing Policy and is provided in Chapter 10, Appendix L.

Mercury impairment determinations are made for each water body by evaluating each applicable water quality standard (each applicable water quality objective supporting the corresponding beneficial use). For example, for many reservoirs only the sport fish water quality objective (see section 1.4.2) would apply and it protects for COMM, WILD and RARE beneficial uses. For example, COMM protects sport fishing, WILD protects kingfishers, and RARE protects bald eagle.

In the absence of applicable water quality objectives, the Listing Policy provides that evaluation guidelines by USEPA or OEHHA may be utilized. The available evaluation guidelines protect only the COMM beneficial use. As a result, the listing of reservoirs as impaired by mercury on the 2010 and subsequent 303(d) Lists are only for COMM and not for WILD and RARE.

The vast majority of California fish methylmercury data is available in sport fish and not in prey fish. As a result, if the Prey Fish Water Quality Objective or California Least Tern Water Quality Objective (see section 1.4.2) apply to a reservoir, it is generally not possible to evaluate whether the WILD and RARE beneficial uses are impaired or non-impaired. It is possible for reservoirs to be placed in multiple categories, e.g., impaired for COMM and non-assessed for WILD and RARE.

Reservoir mercury impairment determinations

As previously described, reservoir mercury impairment determinations are documented in the Integrated Report that is adopted by the State Water Board. Additionally, subsequent to submission of this staff report for scientific peer review, the Mercury Reservoir Provisions and this staff report will be updated to account for additional impaired waters based on analysis that supports mercury impairment determinations for numerous reservoirs (see section 1.6). The revised Provisions and staff report will be distributed to public agencies and members of the public for review and comment.

The next section explains the relationship of the Statewide Mercury Control Program for Reservoirs to existing regional mercury water quality objectives and TMDLs.

1.4.4 State Water Board Statewide Plans Supersede Basin Plans

This section is a placeholder for the staff report that will be developed subsequent to scientific peer review and circulated for public review and comment (see page viii). This section will address legal requirements and describe consequences based on the operation of law that are not derived from scientific findings, conclusions, or assumptions. Therefore, postponement of this discussion is appropriate for purposes of submitting this staff report to scientific peer review.

The State Water Board is authorized to adopt Statewide Plans for waters for which the Clean Water Act requires water quality standards. (Wat. Code, § 13170.) Statewide Plans supersede any other water quality control plan, e.g., Basin Plans adopted by Regional Water Boards, to the extent any conflict exists for the same waters. (Id.) For that reason, when the State Water Board adopts a Statewide Plan, the Statewide Plan automatically has effect for those waters within the respective Regional Water Board's jurisdiction for which a conflict exists—without the respective Regional Water Board having to revise its Basin Plan. Alternatively, if the State Water Board seeks to preserve an existing standard established in a Basin Plan, which would otherwise be superseded by operation of law by the Statewide Plan, the State Water Board's Statewide Plan may expressly except (i.e., exempt) that existing standard so that it remains in effect and is not superseded by the Statewide Plan.

The applicability of the Reservoir Mercury TMDL to reservoirs with USEPA-Established TMDLs

Both the USEPA TMDL and the Reservoir Mercury TMDL will apply to several Los Angeles area reservoirs. The 2010 303(d) List includes three reservoirs in the Los Angeles area for which USEPA previously established mercury TMDLs but were not adopted by the Los Angeles Water Board. Mercury TMDLs for El Dorado Park Lakes, Puddingstone Reservoir, and Lake Sherwood are addressed by the Los Angeles (LA) Area Lakes TMDL for nitrogen, phosphorus, mercury, trash, organochlorine pesticides, and PCBs[4] established by USEPA (2012e). The LA Area

[4] Los Angeles Area Lakes Nitrogen, Phosphorus, Mercury, Trash, Organochlorine Pesticides and PCBs TMDLs, available at: http://epa.gov/region9/water/tmdl/final.html

Lakes TMDL includes a fish tissue methylmercury target[5] of 0.22 milligrams per kilogram (mg/kg) in 350 mm average length largemouth bass, which is equivalent to the target proposed for the Reservoir Mercury TMDL of 0.2 mg/kg (see section 5.1). However, the LA Area Lakes allocations largely address sources of inorganic mercury, but not methylation or bioaccumulation in the reservoir, which the Statewide Mercury Control Program for Reservoirs addresses (see Chapters 5 and 7). Thus, the Statewide Mercury Control Program for Reservoirs is applicable to these three reservoirs.

Supersede mercury TMDL for Hernandez Reservoir in Central Coast Region

The Statewide Mercury Control Program for Reservoirs will apply to Hernandez Reservoir in the Central Coast Region. Previously, the Central Coast Water Board adopted the Clear Creek and Hernandez Reservoir Mercury TMDL. This Central Coast TMDL includes a fish tissue methylmercury target[6] of 0.3 mg/kg (CCRWQCB 2004). This fish tissue methylmercury target is not sufficiently protective of human health and wildlife, and therefore will be replaced by the sport fish target proposed for the Reservoir Mercury TMDL of 0.2 mg/kg. Additionally, allocations in this Central Coast TMDL largely address sources of inorganic mercury, but not methylation or bioaccumulation, which the Statewide Mercury Control Program for Reservoirs addresses (see Chapters 5 and 7). Therefore, when the Reservoir Mercury TMDL is approved by USEPA it will supersede the Central Coast TMDL for Hernandez Reservoir. However, this Central Coast TMDL will remain in place for Clear Creek because it is a creek and the Reservoir Mercury TMDL addresses reservoirs but not creeks.

Existing water quality objectives that will be superseded by the Mercury Objectives Provisions

Currently, some Basin Plans contain mercury or methylmercury water quality objectives that would be superseded by the Mercury Objectives Provisions (see section 1.1 and Chapter 2). Therefore, the Statewide Mercury Control Program for Reservoirs is not designed to achieve objectives planned to be superseded. Section 3.11 of the Staff Report for Statewide Mercury Water Quality Objectives explains that the San Francisco Bay Water Board's chronic mercury aquatic life objective (0.025 micrograms per liter (µg/L)) would be superseded only where it applies to inland surface waters, enclosed bays and estuaries. Section 3.11 also explains that the Central Valley Water Board's body burden objective for mercury would be superseded.

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[5] The LA Area Lakes TMDL also includes water column targets of 0.050 µg/L total mercury for Puddingstone Reservoir and 0.051 µg/L for El Dorado Park Lakes and Lake Sherwood (based on the California Toxics Rule) and water column target of 0.081 nanograms per liter (ng/L) dissolved methylmercury. However, the LA Area Lakes staff report explained that none of the water column samples from these three reservoirs exceeded the total mercury targets. The Statewide Mercury Control Program for Reservoirs includes a methylmercury allocation to the reservoir water column (non-detect methylmercury) that is equivalent to the dissolved methylmercury target.

[6] The Clear Creek and Hernandez Reservoir Mercury TMDL also includes a water column target of 0.050 µg/L total mercury in water (based on the California Toxics Rule as applicable to the municipal supply beneficial use). However, the supporting staff report explained that Hernandez Reservoir is listed as impaired for mercury due to elevated levels of methylmercury in fish tissue, and was achieving water column objectives for mercury. This water column target will be eliminated when this TMDL is superseded by the Statewide Mercury Control Program for Reservoirs.

Existing mercury and methylmercury objectives and TMDLs not superseded

As discussed above, a Statewide Plan that would otherwise supersede standards or programs of implementation established by a Basin Plan may include specific provisions to except such waters—thereby obviating or preventing any conflict in the first instance so that the Statewide Plan and Basin Plan are compatible and not in conflict. To that end, the Staff Report for Statewide Mercury Water Quality Objectives explains which mercury and methylmercury water quality objectives are not superseded.

Moreover, the Mercury Reservoir Provisions expressly provide that they do not apply to any reservoirs for which a Basin Plan established TMDLs or programs of implementation prior to the adoption of the Mercury Reservoir Provisions. Accordingly, reservoirs listed in Table 1.2 are excepted from the Mercury Reservoir Provisions.

The exceptions applicable to the reservoirs listed in Table 1.2 would continue to apply even if the applicable Regional Water Boards subsequently revise such mercury and methylmercury water quality objectives, control programs, and TMDLs.

Streams and rivers only partially addressed

The Reservoir Mercury TMDL includes waste load and load allocations and numeric effluent limitations (NELs) for mercury sources that discharge to creeks and rivers upstream of reservoirs for the sole purpose of addressing the reservoirs' mercury impairment. However, these allocations and NELs may not be sufficient to resolve mercury impairment in the upstream creeks or rivers themselves. Consequently, the Water Boards plan to address mercury-impaired creeks and rivers in future control programs and/or TMDLs as needed.

In summary, the Mercury Reservoir Provisions will be considered for adoption by the State Water Board and it will not supersede any mercury or methylmercury control programs or TMDLs established by the Regional Water Boards for reservoirs listed in Table 1.2. The Mercury Reservoir Provisions will supersede a mercury TMDL for Hernandez Reservoir in the Central Coast Region. Both the USEPA TMDL and the Reservoir Mercury TMDL will apply to three reservoirs in the Los Angeles area.

1.5 Definition of Reservoir and Reservoir Categories for Mercury

This section provides the definition and categories of reservoirs for the Statewide Mercury Control Program for Reservoirs.

1.5.1 Definition of Reservoir

For the Statewide Mercury Control Program for Reservoirs, a reservoir is defined (see glossary in Mercury Reservoir Provisions) as follows:

> A natural or artificial water impoundment that: 1) has constructed structures such as dams, levees, or berms to contain or otherwise manage water, and/or was excavated; and 2) provides year round habitat for fish other than those specifically introduced for vector control purposes.

However, the term reservoir does not include the following types of impoundments, unless the impoundment is expressly identified as a reservoir in a water quality control plan and/or provides year round habitat for fish other than those specifically introduced for vector control purposes:

1. Potable water treatment and storage facilities;
2. Industrial (including mining) supply water treatment facilities including water storage facilities that are part of the industrial process;
3. Ponds or facilities designed and operated to collect or treat municipal, industrial, process or mining waste waters;
4. Storm water runoff and flood control basins containing water ephemerally or intermittently, including constructed storm water detention ponds and storm water best management practice impoundments;
5. Ponds primarily created for purposes of agricultural and ranching operations, irrigation, storage for beneficial reuse, or percolation to groundwater; and
6. Ponds created to impound saline waters, e.g., salt evaporation ponds.

Reservoirs are artificial freshwater lakes that provide wildlife habitat—particularly fish and bird habitat. In other words, reservoirs contain fresh or brackish but not saline water year round and support self-sustaining fish populations. Not all impoundments are artificial lakes—some are simply holding ponds. Impoundments of treated potable water, supply water for industry, and collection of waste waters for treatment are holding ponds. Similarly, ponds primarily created for agriculture (e.g., irrigation), ranching (e.g., stock ponds), storage for beneficial reuse (e.g., tertiary-treated waste water for purple pipe plumbing), or percolation to groundwater are holding ponds that are typically built to serve a specific and single purpose, and rarely are designed or managed to provide habitat and rarely support resident fish populations. Therefore, these waters are not artificial lakes, and so are not reservoirs for the Statewide Mercury Control Program for Reservoirs. Names of actual reservoirs are often misleading; many reservoirs are called lakes on local and U.S. Geological Survey topographic maps even though they are reservoirs because they have constructed structures and/or were excavated.

Most artificial impoundments are reservoirs. Artificial impoundments are places where water ponds behind engineered structures (e.g., dams, levees, berms) and anthropogenic landscape alterations. Some of these constructed changes were made purposefully to create artificial lakes, while others were made for other reasons like dredging or quarrying but subsequently created artificial lakes. Many artificial lakes were formed by flood control and stormwater facilities.

The definition of reservoir for this Statewide Mercury Control Program for Reservoirs is broader than the definition in California Water Code sections 6000–6008. For example, whereas in California Water Code section 6004.5 “reservoirs” impound only waters from dams, in this Statewide Mercury Control Program for Reservoirs “reservoirs” also impound waters from levees, berms, and/or excavations. Also for example, whereas in California Water Code section 6002 dams have minimum height or impounding capacity, this Statewide Mercury Control Program for Reservoirs has no size restrictions.

1.5.2 Mercury Impairment Categories

The Statewide Mercury Control Program for Reservoirs places reservoirs into three categories with respect to mercury impairment, as follows:

Impaired reservoir

An "impaired reservoir" is a reservoir that does not meet water quality standards for mercury pertaining to the COMM, WILD, and RARE beneficial uses. The Mercury Reservoir Provisions defines impaired reservoirs as follows:

> A reservoir identified on Table 1 *[of the Mercury Reservoir Provisions]* that has been determined by the Water Boards to be too degraded to meet water quality standards for the pollutant mercury for COMM, WILD, and/or RARE. The reservoir need not be listed as impaired on the Clean Water Action section 303(d) list of impaired waters.

Even if only one applicable beneficial use of COMM, WILD, and RARE is not supported then the reservoir is categorized as impaired. The Reservoir Mercury TMDL applies to all mercury-impaired reservoirs.

Non-assessed reservoir

A "non-assessed reservoir" is one where information is lacking to make an assessment determination. The Mercury Reservoir Provisions defines "non-assessed reservoir" as:

> A reservoir for which the Water Boards have not determined whether COMM, WILD, and/or RARE is supported for the pollutant mercury (i.e., a non-assessed reservoir is neither an impaired reservoir nor a non-impaired reservoir).

In other words, a non-assessed reservoir is neither an impaired reservoir nor a non-impaired reservoir. Currently, most California reservoirs are categorized as non-assessed due to a lack of fish methylmercury data. Non-assessed reservoirs need not be listed in category 3 in the California Integrated Report.

Non-impaired reservoir

A "non-impaired reservoir" is one that meets water quality standards for mercury pertaining to the COMM, WILD, and RARE beneficial uses. The Mercury Reservoir Provisions defines "non-impaired reservoir" as:

> A reservoir for which the Water Boards have determined that all applicable beneficial uses of COMM, WILD, and RARE are supported for the pollutant mercury.

1.6 Reservoirs and Mercury Impairment Categories in Phase 1

This section describes how individual reservoirs are categorized (see section 1.5.2, Mercury Impairment Categories) for the first phase of implementation ("Phase 1") of the Statewide

Mercury Control Program for Reservoirs. Implementation of this statewide program is planned to proceed in two phases (see Chapter 9, Implementation Plan). Phase 1 consists of mercury source controls for all impaired reservoirs and pilot tests in a subset of impaired reservoirs. Reservoirs that are part of hydropower projects licensed by the Federal Energy Regulatory Commission ("FERC-licensed") would be excluded from mercury pilot test requirements in Phase 1. Phase 1 is expected to last for 10 years, after which the State Water Board would undertake a program review (see Chapter 9). This program review would determine effective and feasible reservoir management actions based on results of the reservoir pilot tests (described below) and would develop Phase 2 implementation actions. Moreover, during program review, the State Water Board would determine if reservoirs should be placed into different mercury impairment categories (see section 1.8). Lastly, this section names specific reservoirs with mercury impairments that are already addressed by a mercury TMDL and so are excepted from the Statewide Mercury Control Program for reservoirs.

The Mercury Reservoir Provisions will place reservoirs into mercury impairment categories that will be fixed for the duration of Phase 1. Preliminary lists of reservoirs for Phase 1 are presented in Table 1.3 (impaired reservoirs; Table 1 in Mercury Reservoir Provisions), and Table 1.4 (non-impaired reservoirs; Table 2 in Mercury Reservoir Provisions) and discussed in detail in this section. All other California reservoirs are categorized as non-assessed.

1.6.1 Impaired reservoirs in Phase 1

Subsequent to scientific peer review, the list of impaired reservoirs in Table 1.3 (and Table 1 in Mercury Reservoir Provisions) will be updated to include additional impaired waters based on analysis of available data. Currently, Table 1.3 includes 74 reservoirs on the 2010 303(d) List. The update will add about 45 reservoirs on 2012, 2014, and 2016 303(d) Lists, and about 30 reservoirs anticipated to be identified based on analysis that supports mercury impairment determinations, for a total of approximately 150 impaired reservoirs.

Impaired reservoirs on the 2010 303(d) List in Phase 1

The 2010 303(d) List includes 74 reservoirs impaired by mercury (Table 1.3 herein; Table 1 in Mercury Reservoir Provisions) for which TMDLs have not been adopted by the applicable Regional Water Board. These 74 reservoirs have been determined by the State Water Board to be impaired for mercury for the COMM beneficial use on the 303(d) List.

These 74 2010 303(d)-listed reservoirs are the group of impaired reservoirs identified for scientific peer review purposes. In accordance with the federal Clean Water Act section 303(d)(1)(A), the Reservoir Mercury TMDL (see section 1.1 and Chapter 8) addresses their mercury impairment. Figure 1.1 illustrates the locations of these 74 mercury-impaired reservoirs, and Table 1.3 lists the reservoir names and owners.

The 74 reservoirs on the 2010 303(d) List meet the definition of reservoir for the Statewide Mercury Control Program for Reservoirs (section 1.5). Of these 74 reservoirs, 69 have dams and 5 are excavations, all 74 contain fish, and none are an excluded type of impoundment.

The mercury impairments in the 74 reservoirs on the 2010 303(d) List are due to elevated fish methylmercury levels[7] for the COMM beneficial use. See section 1.7.3 regarding 4 reservoirs that do not support the COMM beneficial use. See section 1.7.4 regarding a future evaluation as to whether these 74 are also impaired for the WILD and RARE beneficial uses.

Impaired reservoirs on the 2012, 2014, and 2016 303(d) Lists in Phase 1

This staff report will be revised subsequent to scientific peer review to include about 45 additional reservoirs impaired by mercury for which TMDLs have not been adopted by the applicable Regional Water Board. Several of these 45 reservoirs have been determined by the State Water Board to be impaired for mercury for the COMM beneficial use on the 2012 303(d) List. The remainder of these 45 reservoirs are anticipated to be determined by the State Water Board to be impaired for mercury for the COMM beneficial use on the 2014 and 2016 303(d) Lists before revision of this staff report subsequent to scientific peer review.

The additional reservoirs that meet the definition of reservoir (see section 1.5.1) will be added to Table 1.3 in this staff report (and added to Table 1 in Mercury Reservoir Provisions). Additionally and as needed, staff will evaluate whether beneficial uses should be designated, determine reservoir owner and operator, and other evaluations described in section 1.8 and to be included in the staff report.

Additional impaired reservoirs not on 303(d) Lists in Phase 1

This section is a placeholder for the staff report that will be developed subsequent to scientific peer review and circulated for public review and comment (see page xx). This section will address legal requirements and describe consequences based on the operation of law that are not derived from scientific findings, conclusions, or assumptions. Therefore, postponement of this discussion is appropriate for purposes of submitting this staff report to scientific peer review.

A Water Board's determination of mercury impairment is made by applying the Listing Policy's listing factors (as discussed in section 1.4.3 and in more detail in Chapter 10) for the beneficial uses COMM, WILD, and RARE, as applicable.

This section will provide justification for the State Water Board to determine that additional reservoirs are impaired by mercury for COMM, WILD, and/or RARE, and will be included in Table 1.3 herein (Table 1 in Mercury Reservoir Provisions) for which TMDLs have not been adopted by the applicable Regional Water Board. In accordance with California's Porter-Cologne Water Quality Control Act section 13242, their mercury impairment will be addressed by the program of implementation for the Statewide Mercury Control Program for Reservoirs (see Chapters 8, 9, and 10). Existing data indicates that about 30 additional reservoirs are impaired by mercury for COMM.

[7] For 303(d) listing details please refer to State Water Board's 2010 Integrated Report (Clean Water Act section 303(d) List / 305(b) Report) available at: http://www.waterboards.ca.gov/water_issues/programs/tmdl/integrated2010.shtml

If the data analysis indicates impairment, staff will evaluate whether they meet the definition of reservoir (see section 1.5.1), and if they do meet the definition they will be added to Table 1.3 in the staff report that will be developed subsequent to scientific peer review (Table 1 in Mercury Reservoir Provisions). Additionally and as needed, staff will evaluate whether beneficial uses should be designated, determine reservoir owner and operator, and other evaluations described in section 1.8 and to be included in the staff report that will be developed subsequent to scientific peer review.

1.6.2 Non-assessed reservoirs in Phase 1

Most California reservoirs are in the non-assessed category simply because there are no fish mercury data. Although reservoirs do not need to be expressly placed by the Water Boards in the non-assessed category, the Water Boards have placed some reservoirs into this category. For example, the 2012 Integrated Report was the first Integrated Report to include some non-assessed reservoirs (i.e., some reservoirs were placed into category 3 as non-assessed for mercury in the 2012 Integrated Report).

1.6.3 Non-impaired reservoirs in Phase 1

This section is a placeholder for the staff report that will be developed subsequent to scientific peer review and circulated for public review and comment (see page xx). This section will address legal requirements and describe consequences based on the operation of law that are not derived from scientific findings, conclusions, or assumptions. Therefore, postponement of this discussion is appropriate for purposes of submitting this staff report to scientific peer review.

A Water Board's determination of mercury non-impairment is made by applying the Listing Policy's delisting factors (as discussed in section 1.4.3 and in more detail in Chapter 10) for the beneficial uses COMM, WILD, and RARE, as applicable.

This section will provide justification for the State Water Board to determine that additional reservoirs are not impaired by mercury for COMM, WILD, and/or RARE, and will be included in Table 1.4 herein (Table 2 in Mercury Reservoir Provisions).

For example, the 2010 Integrated Report includes 5 lakes or reservoirs in categories 1 and 2 as non-impaired for mercury for COMM. Staff will evaluate whether these 5 are also non-impaired for WILD and RARE (see section 1.7.4). If these 5 are non-impaired, staff will evaluate whether they meet the definition of reservoir (see section 1.5.1), and if they do meet the definition they will be included in Table 1.4 herein (Table 2 in Mercury Reservoir Provisions).

1.6.4 Exempt Reservoirs

Section 1.4.4 (Existing mercury and methylmercury objectives and TMDLs not superseded) describes that a few reservoirs listed in Table 1.2 are excepted from the Statewide Mercury Control Program for Reservoirs. In other words, the Reservoir Mercury TMDL does not supersede mercury TMDLs for reservoirs that were previously adopted by Regional Water Boards.

The reservoirs listed in Table 1.2 are excepted because they are already on the 2010 303(d) List as mercury-impaired and their impairment is being addressed by TMDLs previously adopted by the applicable Regional Water Board. Excepted reservoirs are the following:

- In the Central Valley Region:
    - Clear Lake (Lake County);
- In the San Francisco Bay Region:
    - Guadalupe River Watershed (Santa Clara County) reservoirs downstream of Vasona Dam or downstream of New Almaden mining district; and
    - Soulajule Reservoir (Marin County).

Links to documents describing these TMDLs are available at the following State Water Board website: http://www.waterboards.ca.gov/water_issues/programs/mercury/. Although excepted from this Statewide Mercury Control Program for Reservoirs, information developed from some of these reservoirs about mercury sources and managing reservoirs to reduce methylmercury production was used in Chapters 5, 6, and 7. Furthermore, new information developed from excepted reservoirs and made available (e.g., published in technical journals) may be considered, as appropriate, by Water Board staff and others for selecting and evaluating implementation actions for impaired reservoirs (see Chapter 9, Implementation Plan).

1.7 Designation of Beneficial Uses to Impaired Reservoirs in Phase 1

Table 1.1 lists the 74 reservoirs included on the 2010 303(d) List as impaired by mercury along with the associated beneficial uses designated by the applicable Basin Plan, and the corresponding mercury water quality objectives applicable to each reservoir. As can be seen from Table 1.1, many of the mercury-impaired reservoirs are not designated for the COMM beneficial use.

Additionally, on the 2010 303(d) List, the beneficial use category for the mercury impairment regarding human consumption of fish was categorized under the REC-1 (“fishing”) beneficial use, rather than as COMM (a use definition which was developed later than REC-1). As described in the next section, the Mercury Reservoir Provisions will formally designate the COMM beneficial use for the impaired reservoirs (for those reservoirs currently not designated COMM) identified in Table 1.1.

The WILD and RARE beneficial uses include wildlife consumption of fish. As can be seen from Table 1.1, the applicable Basin Plans for the mercury-impaired reservoirs have not designated many reservoirs for the RARE beneficial use and one for WILD. Pursuant to the Mercury Reservoir Provisions, the California least tern mercury water quality objective would only apply to reservoirs for which the respective Regional Water Board designated the reservoir with the RARE use and for which Department of Fish and Wildlife has reported that that reservoir provides habitat for California least tern. At the time of the development of this staff report, the mercury water quality objective established for RARE would not apply to any of the 74 reservoirs because none provides habitat for California least tern (see section 2.5).

As with the COMM beneficial use, the Mercury Reservoir Provisions will formally designate the WILD beneficial use for the impaired reservoir identified in Table 1.1.

The following sections (1.7.1 – 1.7.4) are placeholders for the staff report that will be developed subsequent to scientific peer review and circulated for public review and comment (see page xx). Nonetheless, this section describes the basis for designation of beneficial uses, and therefore this discussion is appropriate for purposes of submitting this staff report to scientific peer review.

Sections 1.7.1 and 1.7.2 provide justification to designate COMM and WILD beneficial uses where appropriate to reservoirs listed on Table 1.1. Many of the Basin Plans have not formally designated some of the 74 reservoirs on Table 1.1 as having the COMM beneficial use and one Basin Plan has not formally designated 1 reservoir as having the WILD beneficial use. Yet the COMM beneficial use actually occurs at most reservoirs and the WILD beneficial use actually occurs at all 74 reservoirs.

Sections 1.7.3 and 1.7.4 provide justification for the State Water Board to make mercury impairment determinations for reservoirs to be included in Phase 1 of implementation.

The procedures described in sections 1.7.1 and 1.7.2 will also be followed to designate COMM, WILD, and RARE to the impaired reservoirs on the 2012, 2014, and 2016 303(d) Lists in Phase 1 and additional impaired reservoirs (see section 1.6.1), if necessary. Similarly, the procedures described in sections 1.7.3 and 1.7.4 will also be followed to assign impairment categories and provide specificity as to which beneficial uses are impaired, if necessary.

1.7.1 Designate COMM Beneficial Use

This section will describe the basis for the Mercury Reservoir Provisions to designate 54 reservoirs listed as impaired by mercury as also having the COMM beneficial use. Earlier, Basin Plans associated REC-1 with human health (for consumption of fish) because REC-1 includes "fishing" as a recreational use that assumed consumption of the fish caught. Later, the COMM beneficial use definition was revised to add sport fishing. The COMM beneficial use explicitly includes consumption. Therefore, COMM is the correct beneficial use that is impaired by mercury regarding human consumption of fish on a recreational level. The 303(d) listing process did not always evaluate whether the "fishing" recreational use actually *occurred (e.g., discussion included that sport fishing occurs in Lake Shastina[8] but no discussion on whether sport fishing occurs in Calaveras Reservoir[9]).*

As a result, many reservoirs are included on the 2010 303(d) List as mercury-impaired for human fish consumption under the COMM beneficial use category, although the respective Basin Plan may not indicate that COMM is a designated beneficial use. Therefore, the Mercury Reservoir Provisions will designate the reservoirs with COMM and this section will discuss the factual support for the designations.

Factual support for the designations will rely upon information readily available on the internet. The searches will encompass websites including but not limited to the following: CDFW's fishing guide[10], CDFW's Freshwater Sport Fishing Regulations[11], reservoir owner websites, and creel surveys.

The following are examples of factual support that would support a COMM designation and which will be provided for each reservoir to be designated with COMM:

- *Lake Almanor would be designated COMM because CDFW's fishing guide indicates it is a fishing locations; additionally, fishing at Lake Almanor is widely advertised and celebrated as evidenced by existence of a non-profit organization dedicated solely to fishing at this lake (Almanor Fishing Association) that lists numerous fishing guides on its website (http://www.almanorfishingassociation.com/lake_guides.html)*
- *Lake Herman would be designated COMM because—despite not being indicated on CDFW's fishing guide as a fishing location—fishing is allowed although not widely advertised; the local open space district's website mentions fishing at Lake Herman (http://solanoopenspace.org/otheroutdoor.asp)*

The following is an example of factual support that would support not designating a particular reservoir with COMM:

- *Calaveras Reservoir will not be designated COMM because the reservoir owner prohibits fishing.*
    - *The owner adopted a CEQA certified policy called the "Alameda Creek Watershed Management Plan[12]" (ACWM Plan) by resolution. Page 1-21 of the ACWM Plan describes that fishing is not allowed in Calaveras Reservoir;*

[8] Line of evidence (LOE) ID 21168 in 2010 Integrated Report available at: http://www.waterboards.ca.gov/water_issues/programs/tmdl/2010state_ir_reports/00167.shtml#9638

[9] LOE ID 17951 in 2010 Integrated Report available at: http://www.waterboards.ca.gov/water_issues/programs/tmdl/2010state_ir_reports/02505.shtml#17951

[10] CDFW's fishing guide includes an on-line map with blue triangles to indicate fishing locations and fish stocking information, available at: https://map.dfg.ca.gov/fishing/

[11] CDFW's Freshwater Sport Fishing Regulations are updated regularly and available at: https://www.wildlife.ca.gov/regulations

[12] San Francisco Public Utilities Commission, Final Alameda Creek Watershed Management Plan, April 2001; available at: http://sfwater.org/Modules/ShowDocument.aspx?documentID=4348

Chapter 7 contains CEQA Findings and Mitigation Monitoring; and Chapter 8 contains the adopting resolution.

- *Fish methylmercury data were collected from Calaveras Reservoir as part of the SWAMP BOG statewide sampling effort (see Chapter 3). Calaveras Reservoir was 1 of 50 lakes and reservoirs selected by "randomized sampling … to provide an unbiased statewide assessment" in contrast to targeted sampling of 222 popular fishing lakes.*
- *Calaveras Reservoir is not indicated on CDFW's fishing guide as a fishing location.*

Furthermore, staff proposes to add the COMM designation for Central Valley and Santa Ana Regional Water Boards (Regions 5 and 8, respectively) without describing it as a "potential" or "existing" use; e.g., "X" in Table 1.1 for Big Bear Lake. This is consistent with Region 8's Basin Plan, which uses "X" to indicate "existing or potential" beneficial use. Designating a beneficial use in a Basin Plan or Statewide Plan means that the State is obligated to protect that beneficial use. The Water Boards' obligation to protect the use is the same in waters of the United States, regardless of whether the use is identified in a plan as "potential" or "existing." In contrast, the Water Boards' obligation to protect the use in waters within California that are not waters of the United States only occurs for designated beneficial uses. Finally, staff proposes to add the COMM designation for the remaining Regions and describe it as an "existing" use; e.g., "E" in Table 1.1 for Region 2 (San Francisco Bay Regional Water Board) reservoirs, and "filled circle" for Region 9 (San Diego Regional Water Board) reservoirs.

1.7.2 Designate WILD Beneficial Use

O'Neill Forebay will be designated WILD not only because WILD is a presumptive use under the Clean Water Act, but also because the adjacent "O'Neill Forebay Wildlife Area" is managed by the CDFW and it is reasonable to assume that wildlife have ready access to O'Neill Forebay (https://www.wildlife.ca.gov/Lands/Places-to-Visit/ONeill-Forebay-WA).

1.7.3 Impairment Determination for Reservoirs without COMM Beneficial Use

The 74 2010 303(d) impaired reservoirs (Table 1.1) include 4 reservoirs that do not support the COMM beneficial use. However, the 2010 303(d) List evaluated sport fish methylmercury data for human consumption of fish, i.e., only the COMM beneficial use. Therefore, data for these 4 reservoirs will be re-evaluated for protection of WILD and RARE.

The first step in this evaluation is to determine which water quality objective(s) are applicable to each reservoir, recognizing that the applicable beneficial uses are listed on Table 1.1. The California least tern water quality objective does not apply to any of these reservoirs (see Chapter 2). Predatory (trophic level 4) fish are present in 3 of the 4 reservoirs that do not support the COMM beneficial use. As a result, only the sport fish water quality objective applies to 3 of the 4 reservoirs that do not support the COMM beneficial use (as explained in detail in Chapter 2). Both the sport and prey fish water quality objectives apply to Lake Solano, because its highest fish trophic level is 3.

The second step in this evaluation is to compare each reservoir's fish methylmercury data to all applicable water quality objectives. If average mercury levels exceed any applicable objective then the reservoir can be determined to be impaired. All four of these reservoirs are anticipated to be determined to be impaired because the sport fish water quality objective applies to all and is more stringent than the evaluation guideline used for the 2010 303(d) List.

1.7.4 Evaluate Impairment for WILD and RARE Beneficial Uses

Mercury impairment has only been evaluated for the COMM beneficial use for the approximately 150 reservoirs impaired reservoirs in Phase 1 (see section 1.6). Although an impairment determination may occur if water quality is degraded for only one beneficial use, for clarity and completeness, additional columns will be added to Table 1.1 to indicate whether beneficial uses of WILD and RARE are also impaired in each reservoir.

The data evaluation procedures are the same as described in section 1.7.3. The first step is to determine which water quality objective(s) are applicable to each reservoir. The second step in this evaluation is to compare each reservoir's sport and prey fish methylmercury data to all applicable water quality objectives. Average mercury concentrations that exceed the objective indicate impairment, and average mercury concentrations at or below the objective indicate non-impairment. If no impairment determination can be made, which is likely for the prey fish and California least tern water quality objectives, this indicates non-assessed. The results of this evaluation will be presented for each applicable beneficial use.

1.8 Applicability to Impaired Reservoirs in Phase 1 not on 2010 303(d) List

This section is a placeholder for the staff report that will be developed subsequent to scientific peer review and circulated for public review and comment (see page viii). This section will address legal requirements and describe consequences based on the operation of law that are not derived from scientific findings, conclusions, or assumptions. Therefore, postponement of this discussion is appropriate for purposes of submitting this staff report to scientific peer review.

This section pertains to the about 45 reservoirs on 2012, 2014, and 2016 303(d) Lists, and about 30 reservoirs anticipated to be identified as impaired by the staff report that will be developed subsequent to scientific peer review (see section 1.6.1).

The following are the steps to determine reservoir mercury impairment status, and if impaired, to identify corresponding sources of mercury.

<u>Step 1</u>: Water Board staff evaluates whether (a) the water body meets the reservoir definition in section 1.5.1; (b) the available fish methylmercury data are sufficient to characterize risk (e.g., there is an adequate number of samples with adequate quality assurance documentation) to fish consumers (humans and wildlife); and (c) fish methylmercury data exceed water quality objectives. If the answer to each of these three evaluations is "yes," and there is no adopted TMDL or control program, then proceed to step

2. If, however, the answer to (c) is "no" but the answer to (a) and (b) is "yes" and there is no adopted TMDL or control program, then the reservoir can be determined by the State Water Board to be non-impaired.

To determine whether the data are sufficient to characterize risk and whether fish methylmercury data exceed water quality objectives, please refer to Chapter 10.

<u>Step 2</u>: Water Board staff identifies (a) the reservoir owner and operator, including whether federally owned or operated; (b) whether there is a Federal Energy Regulatory Commission (FERC) licensed single-purpose hydropower project on the reservoir; and (c) watershed mercury sources that may require implementation actions.

Chapter 9 describes implementation requirements for watershed mercury sources. Water Board staff will determine whether there are the following watershed mercury sources: mine sites (i.e., historical mercury, gold, or silver mines), NPDES-permitted facilities, and urban runoff. Additionally for urban runoff, Water Board staff will determine the percent of watershed land that is developed, presence of historical mining areas in the watershed, and whether there is a municipal separate storm sewer (MS4) storm drain network that conveys urban runoff into the reservoir or its tributaries. Other mercury sources (e.g., atmospheric deposition) do not require new implementation actions either because actions are already required statewide or for reasons provided in Chapter 7.

<u>Step 3</u>: Water Board staff reviews the beneficial uses designated in the regional Basin Plan. If COMM, WILD, and RARE (for California least tern) are not currently designated, staff evaluates whether any of these beneficial uses should be designated (see section 1.7).

Future applicability

In the future after the completion of Phase 1 of implementation, the State Water Board would undertake a program review and would develop Phase 2 implementation actions. Should the State Water Board proceed with Phase 2 of implementation, it would need to develop lists of impaired and non-impaired reservoirs. The three steps described in the previous section could be taken to determine then-current reservoir mercury impairment status, and if impaired, to identify corresponding sources of mercury.

2 NUMERIC TARGETS

This chapter presents the proposed reservoir mercury Total Maximum Daily Load (TMDL) numeric targets and supports Mercury Reservoirs Provisions Chapter IV.C.1. In a separate project (see sections 1.1 and 1.4), mercury water quality objectives are being developed to protect people who consume fish on a sport or recreational basis and wildlife within all inland surface waters, enclosed bays, and estuaries in California to protect beneficial uses associated with Commercial and Sport Fishing (COMM); Wildlife Habitat (WILD); and Rare, Threatened, or Endangered Species (RARE). The proposed reservoir mercury TMDL numeric targets described below are equal to the mercury water quality objectives and apply to mercury-impaired reservoirs.

2.1 Definition of Numeric Target

Numeric targets are measureable conditions that demonstrate achievement of water quality standards. A numeric target can be a (1) numeric water quality objective, (2) numeric interpretation of a narrative objective, or (3) numeric measure of some other parameter necessary to achieve water quality standards. Mercury targets are the maximum amount of mercury or methylmercury (solid, suspended, liquid, or airborne) allowed in a certain amount of water, fish tissue, or sediments.

The following sections describe proposed and existing numeric and narrative water quality objectives; selection process for targets; and the proposed numeric targets for methylmercury in fish tissue.

2.2 Numeric Water Quality Objectives and Criteria

Numeric objectives for mercury include proposed statewide mercury water quality objectives, criteria established by USEPA for California, and some region-specific objectives.

The derivation of and scientific basis for mercury water quality objectives is provided in the Staff Report for Statewide Mercury Water Quality Objectives (see section 1.1). The statewide objectives are for inland surface waters, enclosed bays, and estuaries, including reservoirs. The proposed statewide objectives and program of implementation do not supersede mercury or methylmercury objectives and corresponding implementation plans or programs of implementation (including TMDLs) where established by a Regional Water Board. The beneficial uses of COMM, WILD, and RARE that these objectives protect are described in Chapter 1. The proposed statewide mercury objectives[1] are the following:

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[1] Statewide mercury objectives apply to marine habitat (MAR) beneficial uses because the Water Quality Control Plan for Inland Surface Waters, Enclosed Bays, and Estuaries of California includes estuarine habitat. Although MAR is not applicable to reservoirs, it is included here for completeness.

2.2.1 Sport Fish Objective

The proposed Sport Fish Water Quality Objective ("sport fish objective") is dependent on fish trophic levels (see Table 2.1), and the Mercury Objectives Provisions defines it as the following:

<u>Applicable Beneficial Uses</u>
The sport fish objective for mercury protects the beneficial uses of COMM, WILD, and MAR. However, in some circumstances (i.e., depending on whether trophic level 3 or trophic level 4 fish applies), with respect to WILD, an additional water quality objective also may apply to protect consumption of fish by all wildlife species.

<u>Sport Fish Objective</u>
The sport fish objective is expressed as follows: The average methylmercury concentrations shall not exceed 0.2 milligrams per kilogram (mg/kg) fish tissue within a calendar year. The water quality objective must be applied to trophic level 3 or trophic level 4 fish, whichever is the highest existing trophic level in the water body. The objective applies to the wet weight concentration in skinless fillet. Freshwater trophic level 3 fish are between 150 to 500 millimeters (mm) in total length and trophic level 4 fish are between 200 to 500 mm in total length, or as additionally limited in size in accordance with the "legal size" set for recreational fishing, established by title 14, California Code of Regulations 14 §§ 1 - 53.03. The size for estuarine fish shall be greater than 150 mm and within the legal size for fishing.[2]

With respect to the WILD and MAR beneficial uses, the sport fish objective is protective of all species only when applied to trophic level 4 fish, except with respect to the California least tern. If the objective is measured using trophic level 3 fish, protection of all wildlife species is not ensured. Therefore, if trophic level 3 fish are used, then one of following objectives must also be measured to determine whether all species within the WILD and MAR beneficial uses are supported: the Prey Fish Water Quality Objective ("prey fish objective") applies, unless the water body is habitat for California least tern, then the Prey Fish Objective for California ("CA") Least Tern ("CA least tern objective") applies. However, if the sport fish objective is exceeded where measured in trophic level 3 fish, that is sufficient evidence to indicate that the prey fish objective or, if applicable, the CA least tern objective is also exceeded without having to measure the objective. (See Figure 2.1)

2.2.2 Prey Fish Objective

The proposed prey fish objective applies to water bodies (a) that do not support California least tern habitat, and (b) where the sport fish objective is measured in trophic level 3 fish, and the Mercury Objectives Provisions defines it as the following:

[2] Although estuaries are not applicable to reservoirs, it is included here for completeness.

Applicable Beneficial Uses

The prey fish objective protects the beneficial use of WILD and MAR. However, the objective does not apply to WILD if the CA least tern objective applies.

Prey Fish Objective

The prey fish objective is expressed as follows: The average methylmercury concentrations shall not exceed 0.05 mg/kg fish tissue from February 1 through July 31, unless site-specific information indicates another appropriate breeding period. The objective applies to the wet weight concentration in whole fish between 50 to 150 mm in total length.

2.2.3 CA Least Tern Objective

The proposed CA least tern objective applies to water bodies that support California least tern habitat and the Mercury Objectives Provisions defines it as the following:

Applicable Beneficial Uses

The prey fish water quality objective for California least tern protects the beneficial uses of WILD, MAR, and RARE at water bodies where the least tern or least tern habitat exists, including but not limited to those water bodies identified in Table 2.2.

CA Least Tern Objective

The CA least tern objective is expressed as follows: The average methylmercury concentrations shall not exceed 0.03 mg/kg fish tissue from April 1 through August 31. The objective applies to the wet weight concentration in whole fish less than 50 mm total length.

2.2.4 Applicability of Proposed Statewide Mercury Water Quality Objectives to Reservoirs

Mercury water quality objectives are proposed for sport fish, prey fish, and small prey fish where least tern habitat is supported. However, only one or two of these three mercury objectives apply to any particular water body, including to reservoirs (see Figure 2.1).

The sport fish objective protects wildlife because WILD is a presumptive beneficial use. The sport fish objective also applies to reservoirs for which the COMM beneficial use applies to protect human health. Either prey fish objective may also apply to reservoirs to protect wildlife that eats very small fish.

The determination of whether one or no prey fish objective applies to a reservoir is based on two factors: (a) whether the reservoir supports habitat for the California least tern and (b) the fish trophic level measured for the sport fish objective. The sport fish objective applies to either trophic level 3 or 4 fish, whichever is the highest existing trophic level in the reservoir. Tables 2.1, 2.2, and 2.3 provide fish trophic levels, habitat areas for the CA least tern, and a matrix of wildlife species and applicability of sport and prey fish objectives. In short, if the reservoir does support habitat for the CA least tern, then the CA least tern objective and sport fish objectives apply. If the reservoir does not support habitat for the California least tern and the sport fish objective is measured in trophic level 3 fish, then the prey fish objective applies. If the reservoir does not support habitat for the California least tern and the sport fish objective is measured in trophic level 4 fish, then neither prey fish objective applies and only the sport fish objective applies.

2.2.5 Effective Date for Mercury Objectives

After adoption by the State Water Board and approval by California's Office of Administrative Law, these three mercury objectives will be effective upon approval by USEPA.

2.2.6 Existing Criteria and Region-Specific Objectives

The following sections describe the existing federal water quality mercury criteria and several region-specific mercury objectives.

2.2.7 California Toxics Rule

Federal water quality criteria[3] and State water quality objectives for priority pollutants have been established for non-ocean surface waters of California by USEPA and several regional water quality control boards. Federal priority pollutant criteria were promulgated by USEPA in the 1992 National Toxics Rule (NTR) and in the 2000 California Toxics Rule (CTR; Code of Federal Regulations, title 40, § 131.38). The CTR supplements the NTR.

The CTR established two mercury criteria for the protection of human health. For human consumption of water and organisms from waters designated for the municipal and domestic supply (MUN) beneficial use, the CTR limits total recoverable mercury to 50 nanograms per liter (ng/L). For human consumption of organisms only from waters not designated for the MUN beneficial use, the CTR limits total recoverable mercury to 51 ng/L. The CTR mercury criteria are applicable to most reservoirs because most reservoirs are designated for the MUN beneficial use.

The proposed statewide mercury water quality objectives are more stringent than the CTR mercury criteria. The CTR (both for waters designated MUN and not designated MUN) uses a fish consumption rate of less than 20 grams/day (g/d), whereas the mercury objectives are based on a higher fish consumption rate (approximately 32 g/d).

A recent consent decree requires that new mercury criteria, such as mercury water quality objectives, be proposed for RARE for federally-listed species by June 30, 2017 (*Our Children's Earth Foundation et al. v. U.S. Environmental Protection Agency, et al.*, Case No. 3:13-cv-2857-JSW (N.D. Cal., Aug. 25, 2014).). This consent decree is applicable to waters that do not yet have established methylmercury water quality objectives for RARE for federally-listed species. When the USEPA promulgated the CTR, ("prey fish objective") and the National Marine Fisheries Service issued a Biological Opinion that the CTR did not fully address the potential for the bioaccumulation of methylmercury to adversely affect federally-listed species. The USEPA committed to re-evaluate this constituent, but has not yet promulgated new limits. As a result of the consent decree, USEPA must either approve objectives adopted by the State Water Board

[3] "Criteria" under the Clean Water Act are elements of state water quality standards and are expressed as constituent concentrations, levels, or narrative statements, representing a quality of water that supports a particular use and are synonymous with state-adopted "water quality objectives." (Compare 40 CFR §131.3(b) (defining "criteria"), with Wat. Code, § 13050, subd. (h) (defining "water quality objectives").)

or propose new mercury criteria by June 30, 2017 for waters that do have mercury criteria for RARE for federally-listed species.

The mercury water quality objectives will be protective of RARE, which would satisfy the consent decree. As described in the next section, two Regional Water Board Basin Plans contain several previously-established methylmercury water quality objectives for specific waters. USEPA has approved these objectives, which protect federally-listed species. Therefore, the consent decree does not apply to these existing mercury objectives.

2.2.8 Region-Specific Objectives

All Regional Water Board Basin Plans have established numeric water quality objectives for mercury. All Basin Plans include an objective for MUN of 2,000 ng/L, which is the maximum contaminant level allowed in California drinking water in accordance with Table 64431-A in title 22 of the California Code of Regulations.

The San Francisco Bay Regional Water Board (Region 2) has established objectives in its Basin Plan for toxic pollutants in surface waters. The acute toxicity water column objective for mercury is 2,400 ng/L one-hour average for protection of aquatic organisms (i.e., habitat-related beneficial uses, such as Cold Freshwater Habitat (COLD), Warm Freshwater Habitat (WARM), RARE, and WILD). The acute objective will not be superseded by the mercury water quality objectives.

The Region 2 chronic toxicity water column objective for mercury is 25 ng/L four-day average for COMM beneficial use. The chronic objective is based on 1 mg/kg in fish (SFBRWQCB 2006). However, the proposed sport fish objective also protects for COMM and is five times more stringent (0.2 mg/kg). Consequently, Region 2's chronic objective of 25 ng/L four-day average will be superseded by the proposed statewide sport fish objective. Accordingly, once the proposed sport fish objective becomes effective, then Region 2 may revise its Basin Plan for clarity to vacate the 25 ng/L four-day average objective in inland surface waters, enclosed bays, and estuaries to which the statewide objective will apply (see section 1.4.4 and Table 1.3).

The remainder of this section focuses on region-specific mercury objectives applicable to reservoirs and the COMM, WILD, and RARE beneficial uses; this section does not discuss applicability of mercury objectives to other waters (e.g., rivers or bays) or for the MAR beneficial use.

Additionally, Region 2 has established mercury and methylmercury water quality objectives and mercury TMDLs for specific waters, including some reservoirs in the Guadalupe River and Walker Creek watersheds, including, but not limited to, Guadalupe Reservoir, Almaden Reservoir, Calero Reservoir, and Lake Almaden in the Guadalupe River Watershed; and Soulajule Reservoir in the Walker Creek Watershed. These Region 2 mercury and methylmercury site-specific water quality objectives will not be superseded by the statewide mercury water quality objectives (see section 1.4.4). Accordingly, the Region 2 mercury and methylmercury water quality objectives will continue to apply to the several reservoirs listed in Table 1.3.

The Central Coast Regional Water Board (Region 3) has established several mercury water quality objectives[4], most of which will not be superseded by the statewide mercury water quality objectives. The Staff Report for Statewide Mercury Water Quality Objectives in section 3.11 explains that Region 3's body burden objective will be superseded for WILD by the sport and prey fish objectives. However, Region 3 has not established mercury water quality objectives for COMM, WILD, and RARE. Accordingly, once the statewide objectives become effective, they will apply to reservoirs in Region 3 with any beneficial uses of COMM, WILD, and RARE.

The Central Valley Regional Water Board (Region 5) has established objectives in its Basin Plan for toxic pollutants in surface waters. Although Region 5 has site-specific water column mercury objectives for Sulphur Creek in Colusa County, these objectives do not apply to any reservoirs.

Additionally, Region 5 has established site-specific methylmercury water quality objectives and methylmercury and mercury TMDLs for specific waters, including Clear Lake. The Region 5 methylmercury water quality objectives will not be superseded by the proposed statewide mercury objectives (see section 1.4.4). Accordingly, the Region 5 methylmercury water quality objectives will continue to apply to Clear Lake.

Regions 1 (North Coast), 4 (Los Angeles), 6 (Lahontan), 7 (Colorado River), 8 (Santa Ana), and 9 (San Diego) have not established mercury water quality objectives for COMM, WILD, and RARE.

Once the proposed statewide mercury objectives become effective, they will apply to all reservoirs in California that do not have site-specific mercury or methylmercury water quality objectives for COMM, WILD, or RARE.

2.3 Narrative Water Quality Objectives

Narrative objectives applicable to mercury include toxicity and bioaccumulation.

2.3.1 Toxicity Region-Specific Objectives

Regarding toxicity, all Basin Plans contain narrative objectives for toxicity that require all inland waters to be maintained free of toxic substances in concentrations that are harmful to human, plant, animal, or aquatic life.

2.3.2 Bioaccumulation Region-Specific Objectives

[4] Region 3 has mercury objectives for AGR use in livestock watering of 10,000 ng/L. Region 3 also has mercury objectives for COLD and WARM of (a) 200 ng/L not to be exceeded, (b) 50 ng/L not to be exceeded on average, and (c) maximum concentration of total mercury in any aquatic organism of total body burden of 500 micrograms per gram wet weight. Note that the Region 3 Basin Plan currently states the aquatic organism objective as "maximum concentration of total mercury in any aquatic organism of total B.O.D. [*sic*] burden of 500 ng/L [*sic*] wet weight." The Basin Plan will be updated to correct minor typographical errors.

Regarding bioaccumulation, three of the ten Basin Plans contain narrative objectives for bioaccumulation, as follows:

- San Francisco Bay Region: “Many pollutants can accumulate on particles, in sediment, or bioaccumulate in fish and other aquatic organisms. Controllable water quality factors shall not cause a detrimental increase in concentrations of toxic substances found in bottom sediments or aquatic life. Effects on aquatic organisms, wildlife, and human health will be considered.”
- Los Angeles Region: “Many pollutants can bioaccumulate in fish and other aquatic organisms at levels which are harmful for both the organisms as well as organisms that prey upon these species (including humans). Toxic pollutants shall not be present at levels that will bioaccumulate in aquatic life to levels which are harmful to aquatic life or human health.”
- Santa Ana River Region: “Toxic substances shall not be discharged at levels that will bioaccumulate in aquatic resources to levels which are harmful to human health. The concentrations of contaminants in waters which are existing or potential sources of drinking water shall not occur at levels that are harmful to human health. The concentrations of toxic pollutants in the water column, sediments or biota shall not adversely affect beneficial uses.”

2.4 Recommend Targets in Fish

Water Board staff considered numeric targets in several media, including biota (fish), sediment, and water column.

Staff proposes numeric targets that are equal to the mercury water quality objectives for COMM, WILD, and RARE beneficial uses because these targets will allow direct assessment of whether beneficial uses are being met. Targets are selected for fish because the principal route for mercury exposure in humans and wildlife is from consumption of mercury-containing fish. Targets are selected for methylmercury because it is the most toxic form of mercury. Additionally, fish methylmercury targets are direct measures of impairment of beneficial uses, whereas sediment and water targets described in the following paragraphs are not robust measures of impairment.

Staff did not select total mercury sediment targets because fish in some reservoirs are impaired for mercury even at background[5] sediment mercury levels. Hence, a total mercury sediment target would need to be below background mercury levels, which is not feasible. Infeasible targets cannot be attained, and therefore are inappropriate TMDL targets. Staff did not select methylmercury targets in sediment because methylation is highly variable in sediments, which would make the target difficult to measure.

[5] Background mercury levels are defined in section 6.2; the many factors in addition to sediment mercury levels that affect methylmercury levels in fish are explained in Chapters 4 and 5.

Staff considered but did not select water column targets. Staff considered a target of 51 ng/L total recoverable mercury in water, which is the mercury criterion for protection of human health for consumption of aquatic organisms under USEPA's CTR. Staff did not select this target because the CTR is based on a lower rate of human consumption of fish than in the mercury water quality objectives. Additionally, staff did not select other concentration thresholds of total mercury in water. Total mercury water column targets would need to be below background for the same reason as for sediment, which is not feasible. While sediment total mercury and aqueous methylmercury are not proposed targets, staff proposes these as allocations as a means to attain the fish methylmercury targets.

Moreover, fish methylmercury provides the most direct link between mercury exposure and the risk from mercury in the aquatic environment. Therefore, fish methylmercury targets are appropriate measureable conditions that demonstrate achievement of water quality standards for mercury in reservoirs. The selected targets are provided in the following section.

2.5 Proposed Numeric Targets

The proposed Reservoir Mercury TMDL numeric targets are equal to the proposed sport fish objective, prey fish objective, and CA least tern objective (see section 2.2 and Figure 2.1). The targets apply to mercury-impaired reservoirs (see Table 1.1) with the same beneficial uses as mercury objectives except for MAR because reservoirs do not impound marine waters. Any changes made to the mercury objectives in response to scientific peer review or public review will also be made to the proposed targets. Changes to the targets may prompt revisions to the Linkage Analysis in Chapter 5.

In accordance with the mercury water quality objectives, staff proposes three targets for the protection of human and wildlife health.

2.5.1 Sport Fish Target

The proposed sport fish target applies to mercury-impaired reservoirs (see Table 1.1) and is expressed by the Mercury Reservoir Provisions as follows:

> The average methylmercury concentrations shall not exceed 0.2 mg/kg fish tissue within a calendar year. The target must be applied to trophic level 3 or trophic level 4 fish, whichever is the highest existing trophic level in the reservoir. The target applies to the wet weight concentration in skinless fillet. Reservoir trophic level 3 fish are between 150 to 500 mm in total length and trophic level 4 fish are between 200 to 500 mm in total length, except for sizes specified in Table 2.1 for the sport fish objective, or as additionally limited in size in accordance with the "legal size" set for recreational fishing established by title 14, California Code of Regulations 14 §§ 1 - 53.03.

2.5.2 Prey Fish Target

The proposed prey fish target applies to mercury-impaired reservoirs (a) that do not support California least tern habitat and (b) where the sport fish objective is measured in trophic level 3 fish, and is expressed by the Mercury Reservoir Provisions as follows:

> The average methylmercury concentrations shall not exceed 0.05 mg/kg fish tissue from February 1 through July 31, unless site-specific information indicates another appropriate breeding period. The target applies to the wet weight concentration in whole fish between 50 to 150 mm in total length.

2.5.3 CA Least Tern Target

The proposed CA least tern target applies to mercury-impaired reservoirs for which the CA least tern objective applies, including but not limited to those water bodies identified in Table 2.2, and is expressed by the Mercury Reservoir Provisions as follows:

> The average methylmercury concentrations shall not exceed 0.03 mg/kg fish tissue from April 1 through August 31. The target applies to the wet weight concentration in whole fish less than 50 mm total length.

The proposed CA least tern target is not relevant to the 74 reservoirs on the 2010 303(d) List (see Table 1.1) because the California Natural Diversity Database indicates that as of August 2012, the California least tern does not exist in these reservoir watersheds. The proposed CA least tern target would apply to reservoirs determined in the future to be impaired (see section 1.6) where the least tern or least tern habitat exists. More information on data sources for designated critical habitat is provided in the Staff Report for S*tatewide Mercury Water Quality Objectives*.

2.5.1 Sample Collection and Determining Attainment of Targets

Sample collection methods, statistical analysis of monitoring data, and a weight of evidence approach for assessing compliance with the mercury water quality objectives are described in Appendix L. Since the proposed numeric targets are equal to the mercury water quality objectives, attainment of the mercury water quality objectives would also attain the targets. Figure L.1 illustrates the process for determining attainment of the water quality objectives.

2.6 Antidegradation

> *This section is a placeholder for the draft staff report that will be developed to support the Reservoir Mercury Provisions. This section will address legal requirements and describe consequences based on the operation of law that are not derived from scientific findings, conclusions, or assumptions. Therefore, postponement of this discussion is appropriate for purposes of submitting this staff report to scientific peer review.*
>
> *The following is an example of antidegradation for an adopted TMDL. This example is slightly modified for clarity from the Guadalupe River Watershed Mercury TMDL, which like the Reservoirs Mercury TMDL has fish tissue methylmercury targets equal to methylmercury water quality objectives.*
>
> *The proposed TMDL targets must be consistent with antidegradation policies. Title 40 of the Code of Federal Regulations (§ 131.12) contains the federal antidegradation policy, while State Water Resources Control Board Resolution 68-16 contains California's antidegradation policy. These antidegradation policies are intended to protect beneficial uses and the water quality necessary to sustain them. When water quality is sufficient to*

sustain beneficial uses, it cannot be lowered unless doing so is consistent with the maximum benefit to the citizens of California. Even then, water quality must sustain existing beneficial uses.

To be consistent with the antidegradation policies, the numeric targets proposed in this TMDL, taken together, cannot be less stringent than existing water quality objectives. Accordingly, the proposed TMDL targets are consistent with federal and state antidegradation policies for the protection of water quality and beneficial uses.

As described in the section titled "Water Quality Standards Attainment," the proposed numeric targets are as protective as the Basin Plans' narrative water quality objectives for toxicity and bioaccumulation. Because fish methylmercury concentrations already exceed these mercury objectives, attaining the numeric targets would improve current water quality conditions and resolve the bioaccumulation impairment.

2.7 Key Points

- Staff proposes numeric targets that are equal to the mercury water quality objectives for COMM, WILD, and RARE beneficial uses because these targets will allow direct assessment of whether beneficial uses are being met.
- The proposed sport fish target applies to mercury-impaired reservoirs (see Table 1.1) and is expressed as follows:
    - Average methylmercury concentrations shall not exceed 0.2 mg/kg fish tissue within a calendar year. The target must be applied to trophic level 3 or trophic level 4 fish, whichever is the highest existing trophic level in the reservoir. The target applies to the wet weight concentration in skinless fillet. Reservoir trophic level 3 fish are between 150 to 500 mm in total length and trophic level 4 fish are between 200 to 500 mm in total length, except for sizes specified in Table 2.1 for the sport fish objective, or as additionally limited in size in accordance with the "legal size" set for recreational fishing established by title 14, California Code of Regulations 14 §§ 1 - 53.03.
- The proposed prey fish target applies to mercury-impaired reservoirs (a) that do not support California least tern habitat and (b) where the sport fish target is measured in trophic level 3 fish, and is expressed as follows:
    - The average methylmercury concentrations shall not exceed 0.05 mg/kg fish tissue from February 1 through July 31, unless site-specific information indicates another appropriate breeding period. The target applies to the wet weight concentration in whole fish between 50 to 150 mm in total length.
- The proposed CA least tern target applies to mercury-impaired reservoirs for which the CA least tern objective applies, including but not limited to those water bodies identified in Table 2.2, and is expressed as follows:

- The average methylmercury concentrations shall not exceed 0.03 mg/kg fish tissue from April 1 through August 31. The target applies to the wet weight concentration in whole fish less than 50 mm total length.

3 RESERVOIR FISH METHYLERCURY DATA AND WATERSHED CHARACTERISTICS

This chapter describes fish methylmercury levels in nearly 350 California reservoirs, the general characteristics of mercury-impaired reservoirs on the 2010 303(d) List and their watersheds, and the need for a statewide program.

3.1 Fish Methylmercury Concentrations in California's Reservoirs

Water Board staff compiled fish tissue methylmercury data from many sources. This section first summarizes findings from a recent Water Board statewide survey of fish methylmercury levels and compares the results to 0.30 milligrams per kilogram (mg/kg) (wet weight) – the threshold used by the State Water Board in the 2010 section 303(d) listing process. Then, this section provides a comparison of fish methylmercury to the sport fish target of 0.2 mg/kg (see Chapter 2).

3.1.1 SWAMP Statewide Fish Survey

Background

The first statewide survey of methylmercury bioaccumulation in sport fish in California's reservoirs was conducted by the Water Board's Surface Water Ambient Monitoring Program (SWAMP) (Davis et al. 2010) in 2007 and 2008. Some data from the two-year study were incorporated in the 2010 section 303(d) List.

The following is an in-depth summary of the survey findings because the results were crucial in determining the extent of the bioaccumulation problem. Nearly all (about 85%) of the almost 300 sites sampled are reservoirs as defined in section 1.6.1, which includes (1) bodies of water with dams (about 75% of sites sampled), and (2) urban lakes or other constructed lakes or ponds (about 10% of sites sampled). Two hundred and fifty reservoirs were selected because they were popular fishing sites and another 50 sites were selected randomly.

Methodology

The overall goal of the SWAMP survey was to determine whether sport fish in California reservoirs have concentrations of contaminants that are above thresholds for protection of human health for people who consume fish on a sport or recreational basis. Therefore, the survey focused on sampling of indicator species that tend to accumulate the highest concentrations of the contaminants of concern.

The primary target species for methylmercury analysis was black bass, which includes largemouth, spotted, and smallmouth bass species. These are high trophic level species (see section 4.2.1) and have a strong size to methylmercury relationship. For these species, fish were sampled across a wide range of lengths and analyzed as individuals to facilitate estimation of size-standardized methylmercury concentrations ("standardized fish methylmercury concentrations"). The survey authors used regression equations to estimate methylmercury concentrations in 350 mm (total length) largemouth bass for each reservoir. The survey authors selected a standard length of 350 mm because it represents the middle of the typical size distribution above the legal limit of 305 mm (12 in.) for largemouth bass in California.

Some high elevation reservoirs only had one abundant high trophic level species (e.g., brown trout). In these cases, the one species still represented a worst-case indicator for methylmercury and was sampled and analyzed. For such species, fish were analyzed in composites of five individuals. Additionally, the two-year statewide survey compared fish methylmercury results for skinless fillets to three screening levels; herein we discuss one screening level, 0.30 mg/kg (wet weight), the threshold used by the State Water Board in the 2010 section 303(d) listing process.

Regional Differences

The survey authors noted that in spite of California's extensive legacy of historic mercury and gold mining, the degree of mercury contamination in fish in California is not unusual compared to the rest of the country. However, methylmercury accumulation in fish is still a significant problem throughout much of California and is much worse in the historic mercury and gold mining regions in northern California. In fact, reservoirs with the very highest species average methylmercury concentrations (>1 mg/kg) were all in mining-impacted watersheds in northern California.

Though 35% of all California reservoirs surveyed had one or more fish species with an average methylmercury concentration exceeding 0.30 mg/kg, 70% of low elevation (below 2,000 feet) reservoirs in northern California were above 0.30 mg/kg. In contrast, 34% of reservoirs in southern California were above 0.30 mg/kg, while only 3% of high elevation (above 2,000 feet) reservoirs in northern California were above 0.30 mg/kg. Rainbow trout were the most commonly caught species in the high elevation reservoirs in northern California, and as discussed more in the next section, tend to accumulate relatively low methylmercury concentrations.

Species Differences

The survey authors also found variation among fish species. As expected, species with the highest methylmercury concentrations were high trophic level species, with a statewide species average of 0.27 mg/kg or higher in largemouth, smallmouth, and spotted bass, and Sacramento pikeminnow. However, for some of these trophic level 4 species, the averages are based on small sample sizes and therefore are imprecise estimates.

The survey also found variation within fish species. For example, self-sustaining populations of brown trout in two high-elevation reservoirs, Hetch Hetchy Reservoir and Loon Lake, had relatively high methylmercury concentrations in their composite samples (0.30 – 0.96 mg/kg). In contrast, brown trout in nine other high-elevation reservoirs generally had low concentrations around 0.10 mg/kg or less.

Species with moderate methylmercury concentrations were other warm water species such as common carp, channel catfish, black crappie, and bluegill.

Species with low methylmercury concentrations were generally rainbow trout, a cold water species, at 0.05 mg/kg average statewide. Regarding rainbow trout, the authors noted that:

- Rainbow trout generally occupy a lower trophic position and accumulate lower concentrations of methylmercury;
- In many reservoirs, recently planted hatchery fish are part of the catch; and
- A previous study found that rainbow trout from four hatcheries consistently had very low concentrations of methylmercury – all less than 0.023 parts per million (mg/kg) (Grenier et al. 2007).

Low methylmercury concentrations in largemouth bass were found in only 6% of the 143 reservoirs where those fish were sampled (average of 0.07 mg/kg or lower). The authors noted that these low concentrations may be due to variation in ecosystem factors such as water chemistry, productivity, trophic dynamics, or wetland presence, or due to variation in sources, such as an absence of mining influence.

Implications

Even though only a small percentage of reservoirs have low methylmercury concentrations in largemouth bass (average of 0.07 mg/kg or lower), the survey authors noted this does show "it is indeed possible for reservoirs in the California landscape, even those with self-sustaining populations of predators, to not have excessive bioaccumulation of methylmercury, and that a realistic management goal for at least some reservoirs may be to attain concentrations of this magnitude."

The survey authors also stated (pp. 56 – 57), "Available data appear to support a general conceptual model that includes a combination of atmospheric deposition, legacy contamination from mining, and geological sources as the drivers of methylmercury bioaccumulation in California lakes and reservoirs…. Lake biogeochemistry can also greatly dampen or increase the impact of the combined mix of sources. The end result of the interplay of these and other factors is the spatially heterogeneous patchwork of aquatic food web contamination observed in this survey." The Statewide Mercury Control Program for Reservoirs builds on this conceptual model in Chapter 4.

3.1.2 Reservoir Fish Tissue Methylmercury Target Comparison

Background

Although the SWAMP statewide fish survey discussed in section 3.1.1 provided very important information, it did not compare fish methylmercury data to 0.2 mg/kg, the sport fish target. Therefore, staff compiled fish tissue methylmercury data from an additional 50 reservoirs from many sources and compared these data together with the SWAMP survey data to 0.2 mg/kg.

Data show elevated fish methylmercury is a widespread problem in California. As explained herein, almost half of the 350 California reservoirs with data have elevated fish methylmercury levels, i.e., levels that exceed the sport fish target.

Methodology

Staff compiled fish methylmercury data for the 2010 section 303(d)-listed reservoirs and other reservoirs in California from many sources. The two primary data sources are the SWAMP statewide fish survey (see section 3.1.1) and the State Water Board's online California Environmental Data Exchange Network (CEDEN) as of August 2012. These data and their citations are included in a Microsoft Excel file included as Appendix Z.

Fish data were compiled for nearly 350 of California's 1,000 reservoirs (DWR 2010a and 2010b), a scientifically large sample size of about one-third of all reservoirs, making this one of the largest data sets of its kind. As can be seen on Figure 3.1, this comprehensive data set covers all areas of the state.

Virtually all the data were generated from samples of skinless fillets. A small number of samples for Beach Lake were from whole fish and were adjusted by a factor of 1.62 based on ratios observed in fish with mercury data for both fillet and whole fish samples. The data were averaged and compared to 0.2 mg/kg in large, high trophic level fish, which is the sport fish target. Like for the SWAMP statewide fish survey described previously, almost all of the data are for reservoirs, not natural lakes. Consequently, we use the term "reservoirs" to describe them in this summary.

Staff made two sets of calculations for each reservoir with fish methylmercury data for this comparison (see Table 3.1):

- Average methylmercury concentration in trophic level (TL) 4 fish (150 mm to 500 mm of legal catch size)1. If TL4 species were not sampled, staff calculated the average methylmercury concentration in TL3 species.
- Methylmercury concentration in 350 mm standard-size ("standardized") black bass. Staff performed the same type of regression analysis between fish length and methylmercury concentration as that used in the SWAMP survey described in section 3.1.1 (see Chapter 5). If black bass were not sampled at a given reservoir, staff calculated the average methylmercury concentration in the highest trophic level species present (150 mm to 500 mm; see Chapter 5).

Results

Fish methylmercury levels are elevated across the state (see orange and red symbols widespread over California in Figure 3.1). Average top trophic level fish methylmercury concentrations are presented on Figures 3.1 and 3.2. Both average and standardized fish methylmercury concentrations are presented in Table 3.1. (Section 5.1.1 explains that average and standardized are equivalent across the state.) The following discussion of results pertains to standardized concentrations.

[1] Note that fish lengths used to calculate average methylmercury concentrations differ slightly from the sport fish target lengths. Here, trophic level 4 fish range from 150 – 500 mm, whereas target length is 200 – 500 mm.

Nearly half of the 348 reservoirs sampled have standardized fish methylmercury concentrations above the sport fish target of 0.2 mg/kg as can be seen on Figure 3.2A (and listed in Table 3.1). (Figure 3.2B uses data from the San Francisco Bay Region to illustrate a high proportion of reservoirs sampled in the Coast Ranges have standardized fish methylmercury concentrations above the sport fish target.) Of the 149 reservoirs with standardized fish methylmercury concentrations that exceed 0.2 mg/kg, 67 reservoirs are on the 2010 section 303(d) List but do not have a TMDL or other control program established, and seven have established mercury control programs. Furthermore, this means that 75 reservoirs have elevated standardized fish methylmercury concentrations but are not formally determined to be impaired by mercury because they were not included on the 2010 section 303(d) List.

The lowest levels of methylmercury concentrations (all samples less than or equal to 0.10 mg/kg) in TL4 (150 – 500 mm) black bass species with more than 1 sample were found in seven reservoirs. Of the 45 samples, all were from largemouth bass and sampled predominantly as individuals (1 composite). These reservoirs are located in southern California, south of Bakersfield, which supports the concept that higher fish methylmercury concentrations are found predominantly in northern California. While staff has not explored additional hypotheses, it is possible that the reservoir itself contains very low concentrations of methylmercury or that the sampled bass were stocked.

Only TL3 fish were sampled in nearly a third of the reservoirs, indicated by large grey symbols in Figure 3.2A, presumably because TL4 species are not resident. There are few grey symbols above 0.2 mg/kg, which corresponds to the SWAMP survey findings that rainbow trout and recently-planted hatchery fish accumulate lower concentrations of methylmercury. Additionally, in about half of the reservoirs with low fish methylmercury concentrations, even TL4 fish have methylmercury concentrations less than 0.2 mg/kg (small black symbols below 0.2 mg/kg).

These calculations and Figures 3.1 and 3.2 show similar spatial trends as those observed by the SWAMP survey:

- The high elevation Sierra Nevada reservoirs tend to have the lowest fish methylmercury concentrations, generally because they are dominated by trout (a TL3 species);
- The highest fish methylmercury concentrations tend to be in the lower elevation reservoirs in northern California, but not exclusively in historic mining regions (see Figure 6.6 in Chapter 6 for maps of mine locations); and
- There are also numerous reservoirs with fish methylmercury concentrations greater than 0.2 mg/kg in southern California.

Implications

The number of reservoirs known to have fish methylmercury levels elevated above 0.2 mg/kg may soon nearly double as more data are collected for the more than 700 remaining reservoirs. Further, it is likely that nearly half of California’s more than 1,000 reservoirs have elevated fish methylmercury levels based on the fish methylmercury target of 0.2 mg/kg.

3.2 Mercury-Impaired Reservoirs and Watershed Characteristics

There are 74 reservoirs identified as mercury impaired on the 2010 303(d) List for which TMDLs have not yet been adopted by the applicable Regional Water Board. Figure 3.3 shows the locations of these 74 reservoirs and their watersheds. The watersheds of 303(d)-listed reservoirs comprise about a fifth of the entire area of California. However, much of southern California is arid and has few reservoirs; consequently, if this area was removed, the watersheds of 303(d)-listed reservoirs comprise more than a fifth of the area of all reservoir watersheds in California. Hence, the 74 reservoirs are an accurate reflection of reservoir characteristics throughout the state.

The mercury-impaired reservoirs and their watersheds vary widely in size. The total water surface area of impaired reservoirs ranges from about 30 acres for El Dorado Park Lakes to almost 30,000 acres for Shasta Lake. The reservoirs' watershed areas range from less than one square mile for Shadow Cliffs Reservoir and El Dorado Park Lakes to about 7,500 square miles for Shasta Lake. Table 3.2 provides these water surface and watershed areas by reservoir along with land use data, and Table 3.3 summarizes their size distribution. These reservoirs and their watersheds span a variety of topographies, climate regimes, and land uses. The reservoirs have elevations ranging from 3 feet above mean sea level at Beach Lake to almost 7,000 feet above mean sea level at Big Bear Lake with watershed peaks approaching or exceeding 10,000 feet in many of the watersheds.

There are over 1,000 reservoirs in California, based on a count of about 1,400 state and federal jurisdictional dams (Figure 3.4) (DWR 2010a and 2010b). Distinct precipitation and temperature zones characterize California and its many reservoirs (Figures 3.5 and 3.6). The climate along the coast is mild with limited temperature variation; some areas of the coast have frequent summer fog. Inland, however, seasonal temperature often ranges from below freezing to greater than 100° Fahrenheit.

Most of California is marked by only two distinct seasons, a rainy season and a dry season. The rainy season spans from October to May. In general, upper elevations receive more rain and snow and are much cooler than the valleys below. The high mountains—especially at intermediate and high elevations of the Sierra Nevada—can experience intense summertime thunderstorms, and snow can last from November to April. Average precipitation varies greatly from reservoir to reservoir, from less than ten inches at San Luis Reservoir and O'Neill Forebay watersheds, to almost 100 inches in some areas of the Lake Oroville and Shasta Lake watersheds, which experience substantial amounts of precipitation as snow. In addition, precipitation can vary greatly within the larger watersheds. For example, in the Shasta Lake watershed annual precipitation ranges from about 7 inches to about 95 inches.

Vegetation types and land uses vary substantially across California (Figures 3.7 and 3.8) and also amongst the 303(d)-listed reservoir watersheds (Table 3.2). A few mercury-impaired reservoirs have watersheds that are somewhat urbanized, such as Puddingstone Reservoir and Beach Lake, which have watersheds that are more than 30% developed, while most of the 303(d)-listed reservoirs have watersheds that are mostly forested or otherwise rural in nature. Fifty-nine of the 303(d)-listed reservoirs have watersheds that are less than 1% developed. Forests are the primary land cover in many of the 303(d)-listed reservoir watersheds.

Thirty-three of the 74 303(d)-listed reservoirs have watersheds that are more than 50% forested. In contrast, agricultural uses account for very little of the 303(d)-listed reservoir watersheds' area. Eleven of the reservoirs have watersheds with 1 – 8% of their area comprised of cultivated crops, while the rest have less than 1% of their area comprised of cultivated crops. Similarly, five 303(d)-listed reservoirs have watersheds with 1 – 11% of their area comprised of pasture or hay production, while the rest have less than 1% of their area comprised of pasture or hay production.

Although the high population regions in California are downstream of all but a couple 303(d)-listed reservoirs, development of a Statewide Mercury Control Program for Reservoirs will need to consider the potential effects of population growth. California's population nearly doubled between 1970 and 2010 (CDOF 2014b) and is predicted to increase by about a third from 2010 to 2050 (CDOF 2014a and 2014b). Much of the recent population growth has occurred in the major urban areas downstream of reservoirs. However, population growth is not limited to the major urban areas. For example, the population of the Sierra Nevada—home to many of California's water supply and hydropower reservoirs—more than doubled between 1970 and 2010, and is forecast to increase by about two-thirds between 2010 and 2050 (CDOF 2014a and 2014c).

Reservoirs are designed for many different uses, such as power production, drinking and irrigation water supply, flood control, and recreation, and most often they are designed for multiple uses. As a result, there are many different ways reservoirs are managed in California. The type of reservoir and the way it is managed can be affected by spatial, physical, and chemical characteristics, such as, but not limited to, elevation, depth, annual precipitation, geology, and upstream inputs, or a combination of these characteristics.

Water Board staff considered an extensive variety of reservoir and watershed characteristics when developing the linkage analysis, source assessment, and implementation plan. A more detailed review of the following reservoir and watershed characteristics can be found in later chapters:

- Chapters 4 and 5 (Reservoir Mercury Cycling and Bioaccumulation Conceptual Model and Linkage Analysis): Reservoir surface area, surface elevation, average and maximum water depth, reservoir capacity and average storage, reservoir water residence time, number of upstream dams, watershed area, and watershed land uses.
- Chapter 6 (Source Assessment): Watershed soil mercury concentrations, historic mining activities, atmospheric mercury deposition and emission sources, urban areas, and municipal and industrial facility discharges.

3.2.1 Statewide Data Analysis

Staff considered and analyzed statewide data in developing this Statewide Mercury Control Program for Reservoirs. For example, the reservoir fish methylmercury data (see section 3.1) includes 50 reservoirs selected at random around California (plus data from another 250 reservoirs). The reservoir watershed characteristics span all regions of California where reservoirs are present, even though it focuses on 74 reservoirs on the 2010 303(d) List. The linkage analysis (in Chapter 5 and Appendix A) spans a wide range of fish methylmercury levels from very low, to just below the sport fish objective, to much higher than the sport fish objective. The source assessment in Chapter 6 is first based on statewide data and then focused on 74 reservoirs on the 2010 303(d) List. For example, statewide assessment of (a) background mercury levels in soils and sediments, (b) atmospheric mercury deposition, and (c) facility and stormwater discharges subject to NPDES-permits. More information is provided in section 6.1.3. Consequently, the analysis presented in this staff report supports this statewide program.

4 CONCEPTUAL MODEL: THE MERCURY CYCLE AND BIOACCUMULATION

Overview

Chapter Objectives

This chapter presents a literature review that describes the mercury methylation process and subsequent bioaccumulation of methylmercury. Methylmercury concentrations increase to levels that pose risks to human and wildlife health through the processes of bioaccumulation and biomagnification of methylmercury through the food web. The objective of the literature review is to identify factors that affect mercury methylation and bioaccumulation, including specific effects reservoirs have on these processes. Understanding the factors that control the processes of methylation and bioaccumulation is necessary to develop strategies for reducing fish methylmercury in reservoirs.

The first section of this chapter focuses on mercury methylation and factors that control it. The second section focuses on the bioaccumulation process. The final section describes the effects of reservoir creation and limnological conditions on these processes.

Foundation from Previous Chapters

More than 70 reservoirs are designated as impaired by mercury by the U.S. Environmental Protection Agency. The number of reservoirs identified as mercury-impaired is expected to double as new fish tissue monitoring data are collected and evaluated. Some impaired reservoirs have fish methylmercury concentrations only slightly higher than the Total Maximum Daily Load (TMDL) target, while many have highly elevated fish methylmercury concentrations.

Chapter 3 describes that mercury-impaired reservoirs and their watersheds span a variety of sizes, topographies, climate regimes, and land uses. In addition, reservoirs are designed for many different uses, such as power production, drinking and irrigation water supply, flood control, recreation, and most often they are designed for multiple uses. Consequently, there are many different ways reservoirs are managed in California and these management activities may affect mercury methylation and bioaccumulation.

A comprehensive literature review is needed to ensure the linkage analysis (Chapter 5), TMDL allocations (Chapter 8), and implementation plan (Chapter 9) account for the diversity of reservoir and watershed conditions throughout California.

Key Points from Conceptual Model Literature Review

- The primary form of mercury bioaccumulated in fish is methylmercury, and fish primarily acquire their methylmercury through their diet. Through biomagnification, the highest

Overview continued on next page

Overview, continued

levels of methylmercury occur in the highest levels of the food web, and as a result top trophic level fish pose the greatest mercury toxicity risks to fish consumers.

- Many factors influence methylmercury concentrations in reservoir fish because there are many successive steps in mercury cycling, from methylation to bioaccumulation in fish.
- New reservoir flooding creates a spike in methylation that lasts for up to 15 years, and elevated methylmercury concentrations in biota can last up to 35 years before declining to a steady-state value. The majority of California reservoirs are older than 50 years, indicating methylmercury concentrations have reached steady-state values. Consequently, current mercury sources and in-reservoir methylation and bioaccumulation are persistent contributors to elevated fish methylmercury levels in California reservoirs.
- Reservoir fish methylmercury concentrations are regulated by a complex web of interactions. Factors that have the greatest influence on fish tissue methylmercury concentrations appear to control either methylmercury production rates or the transfer of methylmercury through the food web.
- A reservoir's aqueous methylmercury concentration is likely the single most important factor in determining the reservoir's fish tissue methylmercury concentration. Factors that have the greatest control over methylation in a reservoir are inorganic mercury sources, organic carbon content, water chemistry conditions in the reservoir (e.g., stratification, anoxia, pH, redox potential), and demethylation rates.
- The transfer of methylmercury through the food web is most influenced by primary productivity, secondary productivity, food web length, fish species present, and fisheries management. Fisheries management increases the mercury toxicity risk to fish consumers by supporting a larger abundance and distribution of top trophic level fish.

Implications

TMDL linkage analyses often focus on the linkage between fish methylmercury and inorganic mercury sources. However, this conceptual model literature review identifies a variety of reservoir and watershed factors that affect methylation and bioaccumulation and are evaluated by the linkage analysis. Although evaluating multiple factors complicates the linkage analysis, doing so enables the creation of more effective mercury source reduction strategies and increases opportunities for innovative techniques to reduce fish methylmercury concentrations more effectively and quickly than through source control alone.

4.1 The Mercury Cycle

The following sections describe the mercury methylation process and factors that affect it. Figure 4.1 depicts this process in reservoirs.

4.1.1 The Mercury Methylation Process: Inorganic Mercury Transforms to Aqueous Methylmercury

Mercury (Hg) can exist in various forms in the environment both physically and chemically. Physically, mercury can exist in water in a dissolved form, but due to its highly hydrophobic nature, it is typically in a 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 either (1) inorganic compounds such as cinnabar (HgS), or (2) more toxic organic compounds such as monomethylmercury (CH_3Hg^{+}). For simplicity, this report uses “methylmercury” rather than monomethylmercury.

In the aquatic environment, mercury is methylated into methylmercury most commonly by anaerobic sulfate-reducing bacteria primarily at the sediment-water interface, but also in anoxic waters. Other bacteria, such as iron-reducing bacteria, also are known to methylate mercury to a lesser degree than anaerobic sulfate-reducing bacteria. Methylmercury can diffuse out of sediment porewater and bind to organic matter in suspended particulates and detrital matter, or it can be absorbed by phytoplankton directly from water. Methylation can occur in both lake sediment and in upstream river banks and wetlands.

Total mercury in water and sediment is largely in the form of inorganic mercury, with only a small percentage of methylmercury (which is organic). As a result, total mercury is often reported in environmental samples as a surrogate for inorganic mercury concentrations. Conversely, the mercury in whole fish or fish fillets is largely in the form of methylmercury. Fish have substantially more methylmercury than inorganic mercury because methylmercury is more readily retained in the cells of phytoplankton and subsequently is transferred and retained in animals further up the food chain (Morel et al. 1998). Because the vast majority of mercury in fish is methylmercury, total mercury is measured in fish as a surrogate for methylmercury for ease and cost of sample collection and analyses.

In summary, the largest proportion of mercury in water and sediment is in the form of inorganic mercury; however, because methylmercury is more readily retained and transferred in biota, the largest percentage of mercury in biota is in the form of methylmercury. Methylmercury is primarily produced by anaerobic sulphate-reducing bacteria, so aquatic environments that promote conditions such as anoxia, stimulate methylmercury production.

4.1.2 Factors Affecting Aqueous Methylmercury Concentrations

Mercury is naturally ubiquitous in the environment; however, anthropogenic activities and other factors can increase its bioavailability and transport to the aquatic environment. These anthropogenic activities and factors influence the rate of methylation, and they are discussed below.

Inorganic Mercury Concentration in Sediment

Aqueous methylmercury concentrations are positively associated with inorganic mercury concentrations in sediment, according to the conceptual model developed for the Guadalupe River Watershed Mercury TMDL (Tetra Tech 2005a) and data from other California reservoirs (Negrey and Stephenson 2010; Negrey 2011; Melwani et al. 2011). Inorganic mercury content of sediment influences methylmercury production by bacteria, which ultimately influences aqueous methylmercury concentration. However, the correlations are weak, which suggests that other factors are as or more important than sediment inorganic mercury concentrations.

For example, methylmercury production increased with increasing inorganic mercury concentrations in laboratory amended sediment (Bloom 2003; Rudd et al. 1983). Likewise, methylmercury concentrations adjusted for organic content of 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 sediment inorganic mercury and methylmercury relationships in the laboratory and environmental sediments were linear to about 1 mg/kg before starting to level off.

Also, aqueous methylmercury increased with water depth in a boreal lake, and the authors suggested that the methylmercury was formed in sediment (Sellers et al. 2001). Aqueous methylmercury also generally increased with depth in the hypolimnion (areas of low oxygen during summer stratification) in Guadalupe River watershed reservoirs. In addition, statistically significant positive correlations have been observed between inorganic mercury and methylmercury in Sacramento–San Joaquin River Delta sediment when adjusted for land use type (e.g., marshes) (Heim et al. 2003). Not surprisingly, though, Tate (2011) found that total mercury sediment concentrations collected in a national lake study were poor predictors of sediment methylmercury concentrations, which suggests that other factors may be more important.

Inorganic Mercury Concentration in Water

The concentration of inorganic mercury in the water column is also important in determining aqueous methylmercury in lakes and reservoirs. For example, in a study of 90 high altitude lakes in the western United States, Krabbenhoft and others (2002) found that aqueous methylmercury concentrations were most strongly correlated with aqueous total mercury concentrations, and that inorganic loading is a primary factor controlling methylmercury production in mountain lakes. In addition, a California reservoir mercury accumulation study also found that aqueous methylmercury was positively correlated with inorganic mercury concentrations in water (Negrey and Stephenson 2010; Negrey et al. 2011; Melwani et al. 2011). The particulate bound inorganic mercury will eventually settle to the bottom of reservoirs, and it can be the main driver of sediment inorganic mercury concentrations.

Bioavailability of Inorganic Mercury

The source will largely determine the oxidation state and bioavailability of inorganic mercury to be methylated into methylmercury. For example, mining waste from mercury mines is typically in the form of cinnabar (mercuric sulfide), which is less likely to become ionized and bioavailable, whereas mercury in gold mining waste is typically in the form of elemental mercury which is more likely to become ionized and bioavailable. Further, mercury deposited from the atmosphere directly on to a water surface is likely the most bioavailable source type, mercury mining waste is likely one of the least bioavailable, and mercury from other sources such as wastewater treatment plants and gold mines falls somewhere in between (e.g., Bloom 2003; Dean and Mason 2009; Heim et al. 2003; Harris et al. 2007; Hintelmann et al. 2002). Dean and Mason's 2009 review of the bioavailability of mercury found that mercury deposited from the atmosphere contains between 15–95% reactive[1] mercury, whereas other sources can be up to 25% reactive but are typically near 5% reactive.

Atmospheric deposition is identified nationally as a major source of mercury to watersheds and a major factor in determining fish methylmercury concentrations. For example, Hammerschmidt and Fitzgerald (2006) observed a statistically significant relationship between annual wet deposition of mercury and standardized largemouth bass methylmercury concentrations in an analysis of 22 states that included California.

At the Experimental Lakes Area, Ontario, Canada, aqueous stable isotope inorganic mercury applied to the lake to simulate atmospheric deposition was quickly assimilated in the fish of the lake as methylmercury (e.g., Mercury Experiment to Assess Atmospheric Loading in Canada and the United States (METAALICUS) study reported by Gilmour et al. 2011, and Harris et al. 2007). The inorganic mercury that was applied directly to the reservoir surfaces was incorporated in higher quantities than the inorganic mercury applied to the watershed. In addition, Evers and others (2007) identified elevated atmospheric mercury deposition as one of the major mechanisms that contributed to biological (fish and bird) mercury hotspots in the northeastern United States and southeastern Canada.

Other source types should not be discounted even though mercury deposition to water surfaces is likely the most bioavailable source type. First, mercury in any form, in the presence of certain water quality conditions, produces methylmercury. As discussed later in this chapter, optimum conditions for methylmercury production frequently exist in and upstream of reservoirs. Furthermore, weathering processes can change the form of mercury from less soluble sources such as mercury mine waste and increase its methylation efficiency as the material is slowly transported away from the source origins to a downstream reservoir (Paquette and Heltz 1995; Wallschläger et al. 1998; Ravichandran et al. 1998). In addition, once ionic inorganic mercury reaches the anoxic hypolimnion, sulfide can dissolve it, resulting in dissolved mercury-sulfide complexes (Watras 2009). These neutrally-charged mercury-sulfide complexes are more bioavailable than ionic inorganic mercury, and can be passively transported across the membranes of sulfate-reducing bacteria. At very high levels of sulfide, however, mercury-polysulfide complexes can be formed, which are negatively charged and less bioavailable for microbial uptake (Benoit et al. 2003).

There is additional evidence that mercury from mines and other less bioavailable sources can result in bioaccumulation. For example, Hunerlach and others (1999) found a positive correlation between mercury bioaccumulation and intensity of hydraulic gold mining. In addition,

[1] In general, includes mercury species that are reducible by the addition of $SnCl_2$ (Dean and Mason 2009).

Slotton and others (1997) found higher food web methylmercury levels in rivers in intensively mined areas in the Sierra Nevada historic gold mining region. Similarly, isotope studies and other evaluations indicate mercury from historic mercury mines in the San Francisco Bay region bioaccumulates in fish (Gehrke et al. 2011; SFBRWQCB 2007).

Finally, as described in Chapter 6, mercury sources are not evenly distributed across the state. Some regions are dominated by mercury mining sources, while others are dominated by gold mining sources or atmospheric deposition. Consequently, relative differences in bioavailability are not germane to these reservoirs.

Wetlands and Other Land Uses

Wetlands are known to be areas with enhanced methylation (Wiener et al. 2003) and sources of methylmercury (Sellers et al. 2001). The presence of wetlands increases a landscape's sensitivity to mercury deposition, and wetlands provide multiple pathways for increased methylation and transport (Driscoll et al. 2007; Evers et al. 2007).

Wood and others' (2010b) review of methylmercury cycling for the Delta TMDL found that the amount of wetlands in a watershed was a key factor in net methylmercury production. However, Tsui and others (2010) found that methylmercury production may also be possible in ecosystems lacking wetlands; they observed methylmercury production within the water column of a stream channel in a California river associated with algal production. The authors hypothesized that *Cladophora* algal mats accommodated mercury methylating microbial communities on algal surfaces.

Other landscapes can also be areas of methylation. Figure 4.2 illustrates methylmercury production (loading) rates associated with a variety of landscapes described in the literature. These include open water areas such as reservoirs and natural lakes, as well as urban, agricultural, and forested areas. The methylmercury loading rates observed for wetlands and reservoirs dwarf methylmercury loading rates associated with all other landscapes. Urban runoff has comparable or higher methylmercury loading rates than runoff from agricultural, forested and other types of landscapes.

Seasonality

Methylmercury production has been found to be highly seasonal (highest in the summer) (Tetra Tech 2005a), often associated with low oxygen zones in the water column of lakes during summer stratification (Eckley et al. 2005; Rudd et al. 1983; Sellers et al. 2001; Slotton et al. 1997; Watras et al. 1995a and 1995b; also see section 4.3.2). In northern Wisconsin lakes, mercury concentrations reflected the seasonal cycle of atmospheric deposition of Hg^{+2} and the annual cycle of microbial methylmercury production (Watras 2009). In addition, a three-fold increase in methylmercury production was observed following the seasonal inundation of an Amazonian floodplain lake (Roulet et al. 2001). Furthermore, Ramlal and others (1993) observed that the ratio of methylation rate to demethylation rate in epilimnetic (shallow) sediments was highest in the warm temperatures of mid-summer, and decreased as the water cooled.

Organic Material in Sediment

Organic material in sediment can be influential in methylmercury cycling, and thus ultimately influential on the aqueous methylmercury concentration. For example, the organic content of sediment has been positively correlated to sediment methylmercury concentrations in Lake Oroville (as total organic carbon, DWR 2006) and in rivers across the United States (as loss-on-ignition, Scudder et al. 2009). Likewise, in Amazonian floodplain sediments, Roulet and others (2001) found that the most important site of methylation was in the organic horizon of the flooded soils. Furthermore, Hall and others (2005) found that experimental reservoirs with the highest amounts of stored organic content had the highest methylmercury production.

In a review of the bioavailability of mercury from different source types, Dean and Mason (2009) concluded that organic matter can enhance methylmercury production by providing a food source to sulfate-reducing bacteria; however, in the same review, they concluded that organic matter can also reduce potential for methylation and bioaccumulation by decreasing the bioavailability of mercury to biota due to complex binding. Overall, organic matter's influence on mercury cycling may largely be dependent on the local environment (e.g. presence of sulfides), as well as the form and quality of organic matter (e.g. charge and number of binding sites).

Dissolved Organic Carbon

Dissolved organic carbon (DOC), like organic material in sediment, is an important factor influencing mercury cycling because DOC concentrations are positively associated with aqueous methylmercury concentrations (Scudder et al. 2009). Indeed, Krabbenhoft and others (2011) concluded that DOC was the key factor controlling aqueous methylmercury concentrations and the ratio of methylmercury to total mercury in over 200 lakes sampled from upper Midwestern states. In the western North America lakes study mentioned earlier, similar correlations between aqueous total mercury and methylmercury with DOC suggested that DOC was likely a principal transport vector or photodemethylation inhibitor rather than a facilitator of methylation (Krabbenhoft et al. 2002).

DOC is a weak acid and will dissolve cinnabar and other complexed forms of mercury. Also, DOC is a strong ligand for inorganic mercury and methylmercury, and it increases their residence time in the water column (Watras 2009). As a result, mercury and DOC can be co-transported to lakes from terrestrial watersheds. DOC can also increase light attenuation, which can result in a reduction of photodemethylation. This reduction of photodemethylation could partially explain the positive associations between DOC and aqueous methylmercury concentrations. Dissolved organic matter plays an important role in determining the speciation, fate, transport, and bioavailability of mercury in the aquatic environment (Ravichandran 2003).

4.1.3 Potential Loss Pathways for Inorganic Mercury and Methylmercury

Both methylmercury and inorganic mercury can be lost from the aquatic reservoir environment in a variety of ways, which are discussed below.

Sedimentation

Sediment-bound mercury commonly becomes trapped in reservoirs through sedimentation, which is when mercury in water settles out of the water column to sit on the reservoir bottom. This mercury can be re-suspended into the water column and thus be available for methylation, or it can be buried by incoming sediment and unavailable for methylation.

Dredging

Mercury can be entirely removed from the reservoir through dredging. However, dredging also can resuspend mercury or uncover previously buried mercury, where it can become bioavailable for methylation and bioaccumulation.

Demethylation and Evasion

Methylmercury can be demethylated back to inorganic mercury, either microbially, or through photodemethylation. Photodemethylation is likely the dominant loss process for methylmercury in freshwaters (Morel et al. 1998; Sellers et al. 1996). Sellers and others (1996) found that photodemethylation rates were dependent on methylmercury concentration and solar light intensity. Once demethylated, the now-free inorganic mercury can be reduced to elemental mercury, where it can be lost to the atmosphere through evasion. Evasion can be a major loss pathway for inorganic mercury for reservoirs.

Dam Releases and Reservoir Flushing

Inorganic mercury and methylmercury suspended in the water column can be transported downstream bound to particulate matter, dissolved, or bound to dissolve organic matter. Likewise, reservoir flushing can release sediment and associated mercury downstream (USBR 2006).

Removal of Biomass

Removal of biomass from a reservoir can occur through intensive fishing or algae harvesting. In some lakes where intensive fishing is practiced, a substantial proportion of methylmercury can be removed. For example, Watras and others (1994) estimated the amount of mercury in lake water, sediment, fish, and other biota using a mass-balance approach for Little Rock Lake, Minnesota. They estimated that fish may contain 33% of the total mercury and 75% of the methylmercury mass in the lake. In all, lake biomass may contain 34–51% of the total mercury and 77–85% of the methylmercury mass in the lake depending on the proportion of seston that is algae. In contrast, Surette and others (2006) estimated that fish may contain less than 2% and 5% of the total mercury and methylmercury, respectively, in three Northern Quebec lakes, also using a mass balance approach.

4.2 Bioaccumulation

The following sections describe the processes of bioaccumulation and biomagnification of methylmercury through the food web and factors that affect these processes.

4.2.1 The Bioaccumulation Process

Methylmercury is a toxic, bioaccumulative pollutant, and hence we employ the term "bioaccumulation" in this report. Pollutants bioaccumulate in an organism when the rate of intake is greater than the organism's ability to remove the substance. Inorganic mercury is absorbed by aquatic organisms at a slower rate and with a lower efficiency than methylmercury, and inorganic mercury is more readily eliminated than methylmercury. As a result, inorganic mercury is not readily transferred through successive trophic levels and does not biomagnify in aquatic or terrestrial food webs as effectively as methylmercury (Wiener et al. 2003). The proportion of mercury that exists as the methylated form generally increases with each level of the food chain, and methylmercury comprises 80% to 100% of the total mercury measured in fish tissue (Becker and Bigham 1995; Bloom 1992; Nichols et al. 1999; Slotton et al. 2004; Sveinsdottir and Mason 2005; Wiener et al. 2003).

Bioconcentration is the net accumulation of mercury by organisms directly from water. Both inorganic and organic mercury can be taken up by aquatic organisms from water, sediments, and food. For instance, low trophic level species such as phytoplankton bioconcentrate their mercury directly from the water through absorption or adsorption. Fish also can absorb mercury through their epidermis (gills, skin, etc.) directly from water; however, fish accumulate the majority of their mercury through their diet in the form of methylmercury (Hall 1997).

Biomagnification, the process where a contaminant concentration increases in each step of the food web, is especially important at the bottom of the food web. This is because the single largest increase in methylmercury concentration in the pelagic food web occurs between water and phytoplankton or seston with a ~100,000-fold increase in methylmercury concentration (Wiener et al. 2003). Subsequent trophic level transfers (e.g., herbivores to zooplankton, prey fish to piscivorous fish) typically have methylmercury concentration increases of only two to five-fold (Figure 4.3).

As a result of biomagnification, the highest concentrations of methylmercury usually are found in large, mature, top trophic level piscivorous fish, such as bass. In a study of California watersheds impacted by gold mining, Slotton and others (1997) observed a pattern of increasing methylmercury concentrations in progressively higher trophic levels of invertebrates. Rainbow trout in the same areas had methylmercury concentrations higher still, while the highest concentrations were found in piscivorous fish. Likewise, Alpers and others (2008) found a systematic increase in methylmercury accumulation with increasing trophic position in Camp Far West Reservoir biota. Top predator bass in California lakes can contain between 1 million and 10 million times more methylmercury on a per weight basis than the water they reside in.

Methylmercury biomagnifies up the food web and causes greatest risk through the consumption of fish. In fact, concentrations of any form of mercury in water typically do not pose risks to human and wildlife health. Through the processes of bioaccumulation and biomagnification of mercury through the food web, methylmercury concentrations increase to levels that pose risks to human and wildlife health.

4.2.2 Factors Affecting Bioaccumulation of Methylmercury in Fish

Understanding the factors (direct and indirect) that control bioaccumulation, in addition to methylation, is necessary to develop strategies for reducing fish methylmercury in reservoirs. Many factors influence methylmercury concentrations in reservoir fish because there are many successive steps in mercury cycling, from methylation to bioaccumulation and biomagnification in fish. Numerous studies have described the factors, discussed below, that control methylmercury concentrations in fish tissue in lakes and reservoirs.

Methylmercury Concentration in Water

Methylmercury concentration in water is a key factor in determining biota methylmercury concentrations (Morel 1998). Statistically significant, positive correlations have been reported between aqueous methylmercury and fish methylmercury (Brumbaugh et al. 2001; Foe et al. 2002; Negrey et al. 2010; Scudder et al. 2009; Tetra Tech, Inc. 2005b; Slotton et al. 2004; Tetra Tech 2005a; Sveinsdottir and Mason 2005; Wiener et al. 2006; Wood et al. 2010b) (Figure 4.4). This relationship has been observed in many different water body types (e.g., rivers, lakes, and reservoirs), and with low and high trophic level fish.

Biota can be highly sensitive to changes in aqueous methylmercury concentrations, and effects in biota methylmercury concentrations have been observed within months of changes in aqueous methylmercury concentrations in California rivers (Figure 4.5). Likewise, seasonal variations in reservoir zooplankton and fish methylmercury concentrations have been observed soon after seasonal variations in reservoir aqueous methylmercury concentrations in California reservoirs (Alpers et al. 2006; Slotton et al. 1995).

Methylmercury and Total Mercury Concentration in Sediment

Methylmercury concentration in sediment is also an important factor in determining fish methylmercury concentrations. For example, sediment methylmercury and spotted bass were collected from different arms of Lake Oroville. Sediment methylmercury concentrations explained approximately 95% of the variability in length-standardized mercury concentrations in spotted bass (Figure 4.6). This suggests that methylmercury produced in Lake Oroville sediment is transferred to the water column and then bioaccumulated by the biota, and that the magnitude of methylmercury produced within the lake has a strong influence on fish methylmercury concentrations. Similarly, total mercury in sediment and water has been shown to have positive relationships with fish methylmercury levels in other reservoirs and water bodies (Wiener et al. 2006; Negrey and Stephenson 2010; Negrey et al. 2011; Melwani et al. 2011; Scudder et al. 2009). This is evidence of the link between inorganic mercury sources and biota methylmercury.

Forested Areas

Evers and others (2007) observed landscapes worldwide and found that forested areas—more than other types of landscapes—capture and transport atmospheric mercury to nearby waters, which results in elevated fish methylmercury levels. For example, Melwani and others (2011) found a positive relationship between mercury concentration in largemouth bass and percentage of forest cover in California reservoirs' upstream watersheds. Likewise, a national study of 291 stream sites across the United States found a positive correlation between percent forest cover, particularly evergreen forests, and predator fish tissue levels (Scudder et al. 2009). In another study, mercury levels in perch from 78 Swedish lakes were strongly influenced by the surrounding land use, and boreal forest lakes had the highest fish methylmercury burdens (Sonesten 2003).

Forests represent areas of long-term storage of atmospherically deposited mercury. Anthropogenic disturbances (e.g., grazing, timber harvest, or recreation) of forests can possibly increase mercury sources to downstream water bodies by mobilizing mercury.

Dissolved Organic Carbon (DOC)

Similar to its influence on mercury levels in water and sediment, organic matter has been found to be influential in biota methylmercury levels. In one example, Garcia and others (2005) found that methylmercury in zooplankton positively matched seasonal variations in lake DOC concentrations. In another study that included 20 Maryland reservoirs, DOC and dissolved methylmercury concentrations were the only two variables significantly correlated to largemouth bass concentrations (Sveinsdottir and Mason 2005). Furthermore, Chen and others (2005) found that DOC, along with three other covariates—pH acid-neutralizing capacity, and sulfate—were common, critical predictors of fish mercury bioaccumulation in northeastern United States lakes.

pH

Multiple studies observed negative relationships with fish methylmercury and pH or acid-neutralizing capacity (Allen et al. 2005; Chen et al. 2005; Wiener et al. 2003; Garcia and Carigan 2000; Stokes and Wren 1987; Watras 2009). For instance, Garcia and Carigan (2000) found that lake pH was the most important predictor of mercury concentrations in northern pike in 19 boreal lakes. Allen and others (2005) also found aquatic biota methylmercury concentrations to be negatively correlated to both pH and hardness.

Some studies observed higher absorption of mercury in fish from water with lower pH (Stokes and Wren 1987). In Wisconsin lakes, fish tended to have higher methylmercury concentrations in lakes with lower pH; yet it was hypothesized that the negative relationship between pH and fish methylmercury is likely the result of factors that co-vary with lake acidification rather than the direct effect of pH on bioaccumulation (Watras 2009).

The hypothesis that pH has influence on methylation agrees with other studies that found pH was negatively correlated to methylmercury in water (Scudder et al. 2009; Watras et al. 1994; Wiener et al. 2006). Likewise, Xun and others (1987) measured increased rates of methylation in water and sediment with lowering pH as part of an experimental lake acidification program. In all, acidity may have an effect on multiple pathways of mercury cycling in the aquatic environment.

Food Web

Food web structure plays a large role in fish methylmercury concentrations because methylmercury is transferred through successive trophic levels, and because fish primarily accumulate all of their mercury from food (Canuel et al. 2009). Low methylmercury levels at the base of the food web and in short food chains yield lower methylmercury levels in top predators.

In addition, lake primary productivity rates or chlorophyll *a* concentration have been found to influence fish methylmercury levels (Allen et al. 2005; Chen and Folt 2005; Kidd et al. 1999; Lange et al. 1993; Melwani et al. 2010; Negrey et al. 2010; Pickhardt et al. 2002; Pickhardt et al. 2005; Simonin et al. 2008). This is logical, since algae are the base of the food web, and the single largest increase in mercury concentrations in the aquatic environment occurs between water and phytoplankton (Wiener et al. 2003; Figure 4.3).

Biodilution, in the form of either algal bloom dilution or somatic growth dilution, may be the mechanism by which primary productivity rates influence fish methylmercury concentrations. Algal bloom dilution occurs when a finite mass of methylmercury is distributed amongst a greater number of algal cells. This dilution results in a lower dietary methylmercury input to algae grazers, which can reduce mercury accumulation throughout the food web (Chen and Folt 2005; Pickhardt et al. 2002; see Appendix A for more).

Moreover, somatic growth dilution occurs when mercury concentration decreases as a result of increased growth rates. Somatic growth dilution, unlike algal bloom dilution, can happen at all levels of the aquatic food chain. This concept is important because inverse relationships between animal growth rates and animal tissue mercury concentrations have been demonstrated using field studies in freshwater systems and bioenergetics modeling (Harris and Bodaly 1998; Lepak et al. 2012; Simoneau et al. 2005). Both algal bloom dilution and somatic growth dilution are discussed in more detail in Appendix A.

Additional factors in the higher levels of the food web, such as species composition, food chain length, and trophic position, influence fish methylmercury concentrations. For example, Plouffe and others (2004) demonstrated that (1) trophic position was a strong determinant of PCB and mercury concentrations in lake trout, and (2) lake trout from lakes with shorter food chain lengths had significantly lower mercury levels than lakes with longer food chain lengths. Thus, food chain length may be an important factor in evaluating site-specific mercury bioaccumulation in California reservoirs.

Further evidence of the influence of food web structure on fish methylmercury concentrations was demonstrated from observations after alterations in lake food webs. First, in Clear Lake, California, threadfin shad invasions resulted in juvenile largemouth bass and bluegill and inland silversides shifting their diets from primarily zooplankton to primarily zoobenthos (Eagles-Smith et al. 2008). Concomitantly, these three fish species' methylmercury concentrations increased by 50%. Second, Kelly and others (2006) attributed five-fold increases in rainbow trout mercury accumulation to a restructuring of the food web after a forest fire. The forest fire increased nutrient loading to the lake, which increased lake productivity and fish growth rates, which in turn increased the consumption of zooplanktivores over detritivores, and led to a longer food chain length. By increasing the length of the food chain, the net amount of methylmercury consumed by the rainbow trout was increased. Before the fire, all fish species primarily consumed invertebrates. Fish switched from feeding on *Hyalella* (a detritivore) before the fire to *Mysis* (a zooplanktivore) after the fire. In addition, rainbow trout, lake trout, bull trout, and cisco consumed young rainbow trout after the fire.

Furthermore, Stow and others (1995) and Jackson (1997) determined that food web dynamics could be manipulated by fisheries management actions such as adjusting predator and prey fish stocking rates, the size of fish stocked, and the species of fish stocked. In those studies, fisheries management actions lowered poly-chlorinated biphenyl (PCB) concentrations, another toxic bioaccumulative pollutant, in common sport fish in the Great Lakes.

In summary, fish methylmercury concentrations are regulated by a complex web of interactions that can influence the rates of methylation or de-methylation or the rates of methylmercury uptake and transfer in biota. Understanding the mechanisms that influence these factors is critical to predicting and reducing fish tissue concentrations in reservoirs. The complexity of mercury cycling facilitates the exploration of several processes (no single fix) to prevent or disrupt mercury accumulation in fish (Mailman et al. 2006).

4.3 The Mercury Cycle Particular to Reservoirs

The following sections describe the mercury methylation process and factors particular to reservoirs.

4.3.1 Reservoir Creation

This section describes the specific effects that reservoir creation (damming and flooding) has on methylmercury contamination. New reservoirs increase methylation and bioaccumulation.

Effects from Flooding of Terrestrial Ecosystems

In recent decades, methylmercury cycling has been studied in newly created reservoirs throughout the world and in California. For example, Abernathy and Cumbie (1977) and Bodaly and others (1984) observed elevated levels of methylmercury in fish in newly flooded hydroelectric reservoirs in Canada. More recently, at the Petit–Saut hydroelectric reservoir in the Amazon, aqueous methylmercury concentrations measured from the outfall of the dam were ten times higher than the river inputs into the reservoir, five years after its creation (Boudou et al. 2005). In addition, methylmercury levels for fish caught just below the dam were eight times higher than fish caught in upstream tributaries.

The flooding of terrestrial ecosystems is the main physical change caused by the creation of reservoirs (Figure 4.7). Researchers found that fish methylmercury concentrations were proportional to the amount of land flooded in Manitoba, Canada reservoirs and in South Dakota lakes (Bodaly et al. 2007; Selch et al. 2007). Likewise, Johnston and others (1991) explained approximately 80% of the variance in reservoir fish methylmercury levels using the ratios of flooded terrestrial area to reservoir water volume for the reservoir itself and for inflowing waters.

Flooding slows water velocity, increases water temperatures, changes water chemistry, and creates conditions that increase the sources and bioavailability of mercury and organic material to the aquatic environment. The flooding of land stimulates the decomposition of organic matter, and this stimulates the activity of methylating bacteria (Bodaly et al. 1984; Hall et al. 2009). In addition, flooding increases the surface area of inundated sediment that can become anoxic, which can enhance methylation.

To determine the mechanisms responsible for elevated methylmercury levels in reservoirs, researchers developed the Flooded Upland Dynamics Experiment (FLUDEX) in the

Experimental Lakes Area Reservoir Project (ELARP) in northwest Ontario, Canada (Bodaly et al. 1984; Bodaly et al. 2007; Hall et al. 2005; St. Louis et al. 2004). Studies found that methylmercury in the soil of experimental lakes that flooded forested areas increased 9- to 70-fold, indicating that flooded soils were the main sites of methylmercury production (Hall et al. 2005; St. Louis et al. 2004). The increase in methylmercury production occurred within the first three years after flooding before returning to near background production rates in about five years. These studies confirmed hypotheses that methylmercury in fish in reservoirs was caused by bacterial methylation of mercury in flooded soils (Bodaly et al. 1984; Bodaly et al. 2007; Hall et al. 2005; St. Louis et al. 2004).

The large surface area of reservoirs increases the area in which atmospheric deposition can deposit mercury directly to the water's surface. This is important because the Mercury Experiment to Assess Atmospheric Loading in Canada and the United States (METAALICUS) study found that mercury that was applied directly to the lake's surface was quickly incorporated into the food web, while less than 1% of the mercury applied to undisturbed upland forests ran off into the lake (Harris et al. 2007; Hintelmann et al. 2002). Methylmercury that accumulated in the food web was produced in the sediment within the lake, and the increase in food web mercury concentrations was proportional to the increased inorganic loading to the lake. In addition, the study confirmed that mercury deposited from the atmosphere is likely more bioavailable (see section 4.1.2) because the newly deposited inorganic mercury was found to be more reactive (a greater percentage of the mercury was methylated) than the native mercury in the lake.

After initial flooding, fish methylmercury levels typically increase between 2- and 7-fold with peak concentrations typically occurring in 5 – 15 years (Genivar 2006; Schetagne et al. 2003; Therrin 2005). In the Canadian La Grande Hydroelectric Complex, elevated mercury concentrations persisted for 10 – 20 years in non-piscivorous fish, and methylmercury levels in piscivorous fish are not expected to decrease back down to natural levels for 25 – 35 years (Schetagne et al. 2003; Therrin and Schetagne 2005). This is consistent with Bodaly and others' (2007) observations, where methylmercury concentrations in higher trophic level fish peaked later and remained elevated longer in Manitoba reservoirs. Thus, observed aqueous methylmercury concentrations in newly flooded reservoirs spike for about ten years, although elevated methylmercury concentrations in fish can remain for decades due to a lag in methylmercury transfer through the food web.

Likewise, others found that elevated methylmercury levels persisted in zooplankton for more than 14 years in a flooded peatland (wetland) experimental lake (Hall et al. 2009). Earlier studies of the same peatland experimental lake measured increases of methylmercury in zooplankton of 10- to 100-fold after impoundment, and methylmercury concentrations in zooplankton, seston, and water were strongly correlated with each other (Paterson et al. 1998).

Some reservoirs can reduce the impact of mercury contamination downstream by trapping mercury-bound sediment. For example, Slotton and others (1997) found that biota downstream of many Sierra reservoirs had statistically significant lower methylmercury concentrations than biota upstream of the reservoirs. They found that the reservoirs were efficient sinks of both methylmercury and inorganic mercury, even though the reservoirs were areas of enhanced methylation. In fact, Englebright and Daguerre Point Dams on the Yuba River were designed to trap sediment and prevent debris from impeding downstream flows and navigation. Alpers and others found that Englebright was a net sink for total mercury, trapping about 40% of total mercury inputs to the reservoir (DFW 2011, page 4.2-41; methylmercury was not assessed). In a separate analysis, Alpers and others (2004) found rapid burial of deposited inorganic mercury and methylmercury in Englebright. In addition, preliminary results for Camp Far West and Rollins Reservoirs in the Bear River watershed suggest these reservoirs may act as net sinks rather than sources of methylmercury to downstream rivers (Alpers 2016 in press).

This differs from the earlier-mentioned Petit–Saut hydroelectric reservoir and the reservoirs in the Guadalupe River watershed, where high levels of methylmercury are discharged downstream (Boudou et al. 2005; Tetra Tech 2005a). Guadalupe River watershed reservoirs discharge high concentrations of methylmercury, and the concentration of methylmercury in the water and biota decreases with increasing distance downstream of the reservoirs. The differences in the transfer of methylmercury downstream are likely from operational differences in the reservoirs. For example, both the Petit-Saut and Guadalupe River watershed reservoirs release water from the hypolimnia, where these reservoirs have elevated levels of methylmercury concentrations. Englebright Dam does not contain a low-level outlet (USACE 2012b), so reservoir discharges may only consist of epilimnion (surface) waters with lower methylmercury concentrations. Slotton and others (1997) hypothesized that the methylmercury produced in the Sierra reservoirs was quickly taken up by the reservoir ecosystem, and thereby unavailable for transport downstream.

Effects from Blocking Salmon Migration

Reservoirs and dams block the return migration of anadromous salmon and their large marine-derived nutrient loads. As described in detail in Appendix A, salmon carcasses are both a food resource for benthic invertebrates and larval fish and, after mineralization, become a nutrient source for benthic and pelagic primary production. Blocking salmon migrations likely contributes to cultural oligotrophication and a concomitant increase in fish methylmercury concentrations. For additional review of the causes of cultural oligotrophication, see section 4.3.2, *Reservoir Water Level Fluctuations*, and Appendix A.

4.3.2 Limnology

This section describes how limnological conditions specific to reservoirs can contribute to mercury impairment. Understanding reservoir-specific limnological conditions is important to developing strategies to lower fish methylmercury levels. Surface water is the “epilimnion” and deep water is the “hypolimnion”; these terms are further defined in the following section that explains thermal stratification.

Studies show that conditions in reservoirs increase mercury methylation and increase bioaccumulation of methylmercury in fish. For example, in Englebright Reservoir, Slotton and others (1997) found that fish in the reservoir had considerably higher methylmercury levels than fish in highly contaminated river areas upstream. They hypothesized that the potential for bacterial methylation is much lower in fast-moving, cold, clear streams as compared to calmer waters of the reservoir. In a study of an Amazonian watershed, Boudou and others (2005) concluded that mercury mobilization from ongoing gold mining in rivers alone was not enough to account for elevated methylmercury concentrations in fish, and that conditions in the reservoir, such as anoxia, were necessary for increased methylation.

Most of the literature suggests that reservoir aqueous methylmercury concentrations are dominated by within-reservoir processes. For example, Sellers and others (2001), using a mass balance approach, found that within-lake production of methylmercury was several times greater than external sources to a Canadian lake. Furthermore, in the Guadalupe River watershed, while the majority of total mercury was transported to the reservoirs during the wet season, the majority of methylmercury was produced in the reservoirs in the dry season (Tetra Tech 2005a). However, the proportional importance of methylmercury sources in a reservoir will depend on local conditions (e.g., abundance of wetlands in the watershed) and reservoir characteristics (e.g., water residence time and thermal stratification). Some reservoir systems may be dominated by upstream inputs, while others may be dominated by reservoir processes.

Five important reservoir-specific processes with potential to increase methylmercury production are described below. These processes are (1) thermal stratification; (2) anoxia; (3) fall turnover; (4) redox potential and sulfate reduction; and (5) reservoir water level fluctuations.

Thermal Stratification

Thermal stratification contributes to anoxia in the water column. Thermal stratification occurs in almost all reservoir impoundments. In shallow reservoirs, the stratification may be relatively weak and ephemeral. In deep reservoirs where storage volume is large compared to inflow, strong stratification develops during the late summer and autumn seasons and may persist for months.

The primary causes of thermal stratification are low thermal conductivity of water, limited penetration of radiant heat and light, and stream inflow temperature. Most heat enters the reservoir through the surface in the form of solar energy. A large percentage of the solar energy is absorbed near the surface, which results in surface waters heating more quickly than the deeper layers. Because warm water is less dense, it remains near the surface, allowing for absorption of more solar energy.

Inflows entering a reservoir may be of different density than reservoir water. The relative densities of the inflow and reservoir waters change seasonally due to changes in temperature and dissolved and suspended solids. Streams may flow into the surface of the reservoir (overflow), along the bottom (underflow), or into an intermediate depth (interflow). The dissolved oxygen concentration of the stream inflow may decrease anoxia during stratification. Stream inflows that are relatively cold with high dissolved oxygen concentrations can even prevent anoxic conditions from forming in the reservoir.

Evaporation will cool the surface layer, causing convection currents. Wind stresses on the water surface cause mixing when an unstable density gradient is set up by surface cooling. These processes of heating, cooling, and wind action lead to the development of a warm, freely circulating, turbulent upper region, called the epilimnion. The epilimnion overlays and insulates the colder, relatively undisturbed deeper waters called the hypolimnion. The depth of the maximum decrease in water temperature is called the thermocline and is found in the water layer called the metalimnion. As illustrated in Figure 4.8, a typical annual thermal cycle in a reservoir includes a nearly isothermal condition in early spring, the development of thermal stratification in spring and summer, and the return to the initial vertically mixed condition in winter.

During midsummer, the daily heat flux causes the thermocline to gradually deepen. However, the density gradient between the epilimnion and the hypolimnion remains strong and stable. In late summer and fall, loss of heat due to falling air temperatures results in a net heat loss from the reservoir. As surface waters cool, their density increases, and the water mixes with the denser water underlying the epilimnion. This unstable situation results in strong vertical mixing called convection. With cooling surface waters and increased winds during fall, the metalimnion erodes from above moving the thermocline deeper. As the reservoir cools further, a point is reached at which the deepening surface layer becomes denser than the bottom layer. Complete mixing of the water column occurs, and is called fall turnover.

The density difference between the surface and deep waters in a thermally stratified reservoir requires considerable mechanical work to mix the entire water column. Significant force is required to lift heavier bottom waters against the force of gravity to mix them with the less dense surface waters. The energy to do this work comes from wind. The interplay between buoyancy and wind-induced turbulence is often expressed as a dimensionless value called the Richardson number (R_i). The Richardson number represents the ratio of buoyancy to shear forces as a function of depth. The Richardson number is a quantitative measure to describe when a reservoir will mix. If a reservoir's Richardson number is greater than the critical level of $R_i = 0.25$, then the reservoir's density layers are stable and resistant to mixing. Lower Richardson numbers (i.e., $R_i < 0.25$) indicate reservoirs with a stronger shear force relative to buoyancy, which results in the mixing of the water column (Chapra 1997).

Reservoirs are classified according to their stratification frequency. Monomictic reservoirs have one mixing period per year. Most reservoirs in California are warm monomictic reservoirs that completely mix during the winter without freezing over, and stratify in the summer. Dimictic reservoirs are stratified when covered with ice during the winter, destratify and mix in spring with ice melt, stratify again during the warm summer, and destratify and over turn as temperatures cool in the fall. Polymictic reservoirs stratify and over turn frequently throughout the year.

Reservoir and watershed morphological characteristics influence the type of stratification cycle in reservoirs. For shallow reservoirs, many exhibit polymictic behavior due to diel temperature changes. Wind energy delivered to the reservoir surface varies according to the height and orientation of the watershed landscape. Wind-driven currents increase mixing and heat transfer. With stronger currents, heat penetrates more deeply lowering the thermocline. For deep reservoirs with large surface areas, currents can be generated from seiche waves caused when the wind blows for an extended period from one direction. The wind piles water up in the lee shore. When the wind stops, the accumulated water mass flows back due to gravity. A standing wave is produced that rocks back and forth with gradually decreasing motion. The movement of water during seiche waves increases mixing and can erode thermal stratification.

Anoxia

Hypolimnetic waters can become depleted of oxygen. Under thermally stratified conditions, the hypolimnion is isolated from the atmosphere by the epilimnetic surface waters. Hypolimnetic and benthic organisms remove dissolved oxygen through respiration and organic carbon decomposition. This lost dissolved oxygen cannot be replenished from the atmosphere due to stratification. Thus, dissolved oxygen concentrations typically mirror the temperature profile with depth. Dissolved oxygen concentrations high in the epilimnion and low in the hypolimnion are called clinograde profiles. An anoxic factor (AnF) was developed for reservoirs by Nürnberg (1995 and 2004) to quantify the extent and duration of anoxia in stratified lakes. This factor is useful to managers of lakes with “reducing conditions” that cause problems such as algal blooms from internal phosphorus releases or water treatment or related problems from iron and manganese. AnF has also been used to manage methylmercury production in Onondaga Lake (Matthews et al. 2013).

Anoxic conditions can greatly affect the water quality of a reservoir. Hypolimnetic enrichment of iron, manganese, phosphorus, sulfides, and ammonia has been observed in association with anoxic conditions in the hypolimnion (Boyd 2005; Beutel 2005; Dent et al. 2014; Watras 2009). For example, hypolimnetic anoxia resulted in the accumulation of hydrogen sulfide and ammonia in Camanche Reservoir, and the accumulated toxins created water quality impairments in the reservoir and downstream fish hatchery (Beutel 2005). Anoxic and reducing conditions (redox potential discussed in next sub-section) convert insoluble oxidized precipitates into reduced soluble forms (Goldman and Horne1984), and as a result these soluble chemicals are released from the sediment.

Hypolimnetic enrichment of inorganic mercury and methylmercury is also observed in the anoxic hypolimnion of lakes and reservoirs (Alpers 2006; Herrin 1998; Regnell et al. 1997; Regnell et al. 2001; Tetra Tech 2005a; Watras 2009). Elevated concentrations of both inorganic mercury and methylmercury in the hypolimnion can reach 10 and 100 times the concentrations in the epilimnion, respectively (Watras 2009). The elevated mercury concentrations co-occur with the release of soluble forms of iron and manganese from hydrous oxides from the sediment (Dent et al. 2014; Regnell et al. 2001; Todorova et al. 2009). In contrast, under oxic conditions the mercury is tightly bound to insoluble metal oxides. Also mentioned previously, sulfides in anoxic conditions can strip ionic mercury from settling particulate matter. Likewise, since methylmercury is primarily created by anaerobic sulfate-reducing bacteria, anoxic conditions stimulate methylation and accumulation of methylmercury in the hypolimnion of reservoirs. Under oxic conditions this hypolimnetic enrichment of mercury is not observed in lakes (Watras 2009).

Though methylmercury is primarily produced in sediment, methylmercury also can be generated in anoxic portions of the water column. For example, Watras and others (1995a and 1995b) studied Wisconsin lakes and found that methylmercury was produced within the water column in a layer of plankton near the top of the anoxic hypolimnion. Maximum concentrations of methylmercury near the top of the anoxic hypolimnion were associated with settling and decomposing algae particulate matter, and maximum rates of net methylation occurred in the same region of the water column where they observed maximum rates of sulfate reduction. They concluded that zones of mercury methylation and sulfate reduction follow the oxic-anoxic boundary in the water column similar to what has been observed in sediment. This is important because anoxic hypolimnia can allow anaerobic metabolism and methylmercury production to occur in the water column and not just in the sediment. Sellers and others (2001) observed a methylmercury concentration peak above the sediment surface; they hypothesized, however, that this accumulation was due to particle settling over increased methylation.

Methylmercury production is not limited to the sediment located in the hypolimnion, and epilimnetic sediment methylmercury production can constitute a large proportion of a reservoir's net methylmercury production. For example, in Canadian oligotrophic lakes, Ramlal and others (1993) measured 20- to 40-fold higher methylation rates in epilimnetic sediment than in hypolimnetic sediments in the summer. In addition, because epilimnetic sediment covered the majority of the lake surface, the authors concluded that most of the in-lake methylmercury production occurs in the epilimnion. Similarly, Sellers and others (2001) found that methylation was not restricted only to the hypolimnion in another Canadian lake. Finally, in the Guadalupe River watershed reservoirs, elevated methylmercury concentrations in the epilimnetic zones indicated that methylation was occurring in the vegetative zones of the sediment; nevertheless, overall, the reservoirs' hypolimnia were producing 10- to 14-fold more methylmercury than the epilimnion (Tetra Tech 2005a).

Fall Turnover

The breakdown of thermal stratification and mixing of hypolimnetic water with the epilimnion during the fall turnover can result in the entrainment of hypolimnetic reduced substances into the upper water column. Loading of these reduced substances to the epilimnion due to entrainment of hypolimnetic water has been found to be much larger than external loading (Soranno et al. 1997). The timing of the hypolimnetic entrainment can have a large effect on the bioaccumulation of methylmercury. Herrin and others (1998) showed that methylmercury from the hypolimnion can quickly be taken up by particulate matter (including phytoplankton and zooplankton) during turnover with a several-fold increase in mercury concentrations. In addition, the methylmercury was readily transferred to larval fish, and the increases to particles, zooplankton, and fish concentrations were related to the mass of methylmercury stored in the hypolimnion. Slotton and others (1995) observed seasonal increases in zooplankton and fish methylmercury concentrations that coincided with the destratification of Davis Creek Reservoir, California.

Fall turnover is not the only time when constituents can be transferred between the hypolimnion and epilimnion. Vertical transport of hypolimnetic methylmercury into epilimnetic waters during stratification can occur and vary depending on the concentration gradients in the hypolimnion. Due to this constant transport of methylmercury from the hypolimnion to the epilimnion throughout the year, aquatic biota can bioaccumulate methylmercury year round.

The degree of vertical transport of hypolimnetic methylmercury into epilimnetic waters can be estimated through modeling (Chapra 1997). Reservoir managers also commonly estimate the vertical transport of other constituents like phosphorus and dissolved oxygen. Numerous factors influence the flux of methylmercury and other constituent mass across the thermocline. These factors include the water temperatures of the epilimnion, hypolimnion, and inflows; density; specific heat; inflow rates to the epilimnion; reservoir surface area; thermocline area;

thermocline thickness; surface heat flux; and the thermocline heat transfer coefficient. Thermocline diffusion coefficient values and mass flux are positively correlated with mean depth and can range over several orders of magnitude (0.003 to 2.4 cm^2/s). However, estimates of mass transport (e.g., of dissolved oxygen) across the thermocline by modeling vertical diffusivity do not account for entrainment of hypolimnetic water into the epilimnion due to physical mixing (Snodgrass 1985).

Reservoir operations can have a large effect on thermal stability (James et al. 2004). For example, reservoirs that discharge from the surface of the reservoir have a shallower epilimnion, larger metalimnion, and cooler temperatures in the hypolimnion, which results in a more stable thermocline. Surface discharges reduce the potential for vertical entrainment of hypolimnetic waters to the epilimnion. Increased flushing rates in the epilimnion may also be effective in removing methylmercury found in the epilimnion due to external loading or production in reservoir as described earlier in this section. Reservoirs that discharge hypolimnetic water result in the continual removal of cooler bottom water and replacement with warmer water originating from reservoir inflows. Discharges from the deeper part of a reservoir cause a weakening of thermal stability and the development of a weak metalimnion, making the reservoir more susceptible to mixing and vertical entrainment of hypolimnetic methylmercury.

Redox Potential and Sulfate Reduction

Anoxia has been identified as a key factor in methylmercury production because sulfate-reducing bacteria—the largest producers of methylmercury—are thought to be strictly anaerobic. In the presence of oxygen (O_2), strictly anaerobic sulfate-reducing bacteria growth is restricted, and the primary mode of organic matter decomposition is from aerobic bacteria metabolism.

Oxygen concentration also restricts sulfate reduction because it has an effect on the oxidation-reduction (redox) potential of the reservoir. The redox potential (E_h) is the measure of electrochemical potential, or electron availability, to all inorganic and organic chemical reactions (Delaune and Reddy 2005). Figure 4.9 shows the relative redox scale and the redox potential ranges for common chemicals in soil and sediment. Redox potential is a relative scale determined by a media's chemical make-up and the chemicals' electrochemical properties.

Redox potential is highly affected by oxygen, as well as pH. Chemicals higher on the redox scale are thermodynamically favored to be reduced or accept electrons, and these chemicals will be reduced before other chemicals lower on the scale (Banchuen 2002; Delaune and Reddy 2005; Gandy et al. 2006).

Oxygen is the strongest oxidizing agent commonly found in nature, and when oxygen is present the redox potential of the media will be above 400 mV. At this redox potential the other chemicals are more stable in their most oxidized forms: Fe^{3+} over Fe^{2+}, Mn^{4+} over Mn^{3+}, NO_3^- over NH_3^-, SO_4^{2-} over HS^-, etc. (Goldman and Horne 1984). As oxygen is depleted, the redox potential begins to drop to ranges where these other chemicals thermodynamically begin to favor their reduced forms. Once oxygen is depleted, (1) anaerobic metabolism can proceed, and (2) the other chemicals will be used as the electron acceptor in sequence of their thermodynamic potential ($NO_3^- > Mn^{4+} > Fe^{3+} > SO_4^{2-}$...). Sulfate reduction and its associated methylation will not be thermodynamically preferred until the other chemicals are reduced and depleted, which then will result in a drop in redox potential.

Muyzer and Stams' (2008) review of the physiology and distribution of sulfate-reducing bacteria suggests that although named for their ability to use sulfate as a terminal electron acceptor, sulfate reducers also can grow by using other electron acceptors like other sulfur compounds, nitrate, and iron. If so, these sulfate-reducing bacteria and possibly other microorganisms would preferentially reduce nitrate and other chemicals higher on the redox scale before sulfate because of the higher potential energy gain (Snoeyink and Jenkins 1980). In addition, methylmercury production through sulfate reduction may be inhibited in the presence of these other chemicals.

Reservoir Water Level Fluctuations

Reservoir water level fluctuations influence the methylmercury levels in biota in lakes and reservoirs. For example, a statistical positive correlation was observed between largemouth bass mercury concentrations and the magnitude of reservoir fluctuations in California reservoirs (Melwani et al. 2011). Evers and others (2007) identified large water level fluctuations, in addition to elevated atmospheric mercury deposition and high landscape sensitivity (e.g., more wetlands), as the major mechanisms in contributing to biological (fish and birds) mercury hotspots in northeastern United States and southeastern Canada. In addition, Sorensen and others (2005) found that Minnesota's Sand Point Lake's change in maximum water level relative to the previous year was a strong predictor of young-of-year yellow perch methylmercury concentrations over a 12-year period. They found many water level metrics (e.g., maximum, mean, range, and change in range) were good predictors of fish methylmercury levels in the lake, as well as in another comparison of 14 other Minnesota lakes. All studies hypothesized that drying and rewetting sediments stimulated methylation.

Using laboratory experiments, Gilmour and others (2004) hypothesized that methylation stimulation from drying and rewetting was likely due to the oxidation of organic matter and sulfate while the sediment was dry. This oxidized material could later fuel bacterial sulfate reduction once the soil was rewetted. Oxygen levels in the rewetted sediments began to decline within 24 hours, and anoxia was fully developed within 5 days.

In the field, Roulet and others (2001) measured methylmercury production in the sediment of an Amazonian floodplain lake and found that seasonal inundation of the shoreline of the lake promoted a three-fold increase in methylmercury production when flooded compared to when it was dry, while the always-flooded lake center showed no seasonal difference. The lake shoreline and upland forest sediments always had higher methylmercury production rates than in-reservoir, open water sediments. Open waters do not support emergent vegetation, but may support floating plants which are not attached to bottom sediments. In addition, methylmercury production in the shoreline and forest sediments was linked to high organic content. The authors stated that data suggested that methylation occurred in the litter and humic layers. Thus, the seasonal inundation of dried sediment may be an important factor influencing methylmercury levels in reservoir fish.

Because of concerns over reservoir level fluctuation effects on mercury bioaccumulation, a study was performed on Lewiston Reservoir (part of the Niagara Power Project in New York) to determine whether its operation enhanced methylation (Tetra Tech 2005b). Lewiston Reservoir is a pumped storage facility for the power project, and it can have daily level fluctuations of 7 − 43% and weekly level fluctuations of 26 − 86% of its maximum reservoir depth; however, Lewiston Reservoir is unique in that the majority of the shoreline that is exposed is covered with riprap. The riprap appeared to reduce the substrate and organic matter that support enhanced microbial activity. The study concluded that the short residence time of the reservoir had the strongest influence on mitigating mercury methylation. The short residence time and high frequency of fluctuations did not allow many of the physical and chemical properties (e.g., warming of water, stratification, oxidation of uncovered sediment, development of anoxia) necessary for microbial activity and methylation to occur.

Large reservoir level fluctuations also may increase mercury bioaccumulation by decreasing benthic primary productivity. Large water fluctuations result in erosion of fine sediments and associated nutrients, which results in denuded and armored reservoir banks that limit benthic primary productivity. This decrease in benthic primary productivity results in decreased growth rates through the food web for organisms dependent on benthic algal production. Large water level fluctuations effectively reverse somatic growth dilution, and this results in higher biota methylmercury concentrations.

The decrease in benthic primary productivity caused by large reservoir water level fluctuations is one of the factors that contribute to cultural oligotrophication of California reservoirs. Cultural oligotrophication is defined as an anthropogenically induced decrease in nutrient concentrations and aquatic primary production (Stockner et al. 2000; Stockner and Ashley 2003). One consequence of cultural oligotrophication is a gradual decline in fish tissue growth rates in impounded water bodies and in downstream water bodies. Cultural oligotrophication and its contributing factors to are discussed in more detail in Appendix A.

In summary, the flooding of terrestrial ecosystems is a major cause of elevated aqueous and fish methylmercury in new reservoirs because flooding causes bacterial stimulation and methylation of mercury present in the soil. In general, elevated methylmercury concentrations in reservoirs persist for about 10 – 15 years, at which time the internal stores of bioavailable mercury become diminished. Non-piscivorous fish methylmercury concentrations return back to natural concentrations in 10 – 20 years, while piscivorous fish methylmercury concentrations return back in 25 – 35 years. In California, approximately 85% of all dams were built over 35 years ago, and the average age is 62 years (median = 57 years) (DWR 2010a and 2010b). This suggests the vast majority of reservoirs in California are likely beyond the influence of the "new" reservoir flooding spike in methylation. Even though this spike of methylation has passed, reservoirs continue to enhance methylmercury production and bioaccumulation by changing thermal stratification and resultant hypolimnetic anoxia, which create conditions favorable to sulfate reduction by anaerobic bacteria. Likewise, water level fluctuations have the ability to create a consistent supply of oxidized material in sediment to aid in sulfate reduction and methylation. In addition, annual water level fluctuations may reduce reservoir benthic primary productivity, which contributes to reduced biota growth rates, leading to increased tissue methylmercury concentrations.

4.3.3 Increased Human Health Risks from Eating Reservoir Fish

Many reservoirs provide easy access for the pubic to be exposed to mercury-contaminated fish. Very few reservoirs are closed to the public, and most have paved access roads and boat ramps. Further, Federal Energy Regulatory Commission (FERC) licensees have a responsibility under the Federal Power Act to provide recreational opportunities at hydroelectric projects under FERC jurisdiction (FERC 1996), including sport fishing. Many FERC-licensed and non-FERC-licensed reservoirs are stocked with fish to provide sport fishing opportunities.

Additionally, many non-native fish species were introduced in California in the late 19^{th} century. There were relatively few native sport and game fish in California, and they were generally small, non-piscivorous fish (Pien 2014; Moyle 2002; McGinnis 2006). Native fishes are able to withstand California's unique natural (and relatively harsh) habitats and include sturgeons, suckers, minnows, sculpins, trout, and salmon. These habitats include cold, fast streams created by melting snow and summer thunderstorms, deeper rivers, intermittent shallow creeks with fluctuating flows, desert springs, and a small number of small and large lakes (McGinnis 2006). Reservoirs and dams altered the California landscape, creating habitat that was less suitable for many native species, or more suitable for many of the introduced species (Pien 2014; Moyle 2002; McGinnis 2006). Further, reservoirs and dams block the return migration of anadromous salmon. Land-locked salmon in reservoirs have much higher methylmercury levels than anadromous salmon, and higher than the sport fish target (Figure 4.10).

Many of the introduced species, such as black bass species, are now self-sustaining populations. These top predator fish are higher in the food web and therefore tend to bioaccumulate more methylmercury and have higher methylmercury concentrations. Fish stocking and fisheries management practices that promote these predatory fish species may increase risks of mercury exposure to reservoir anglers and wildlife.

In addition, because reservoirs create water bodies that contain warmer water than the original streams, they allow for introduced non-native warm water fish to flourish in regions higher in elevation than would be typical. Black bass are a commonly stocked, warm water predatory sport fish that are able to reside at higher elevations in reservoirs than in streams and rivers (Moyle 2002). Likewise, fish stocking has introduced fish in high elevation reservoirs where fish did not exist. For instance, in a Sierra Nevada non-native trout distribution study, Knapp (1996) determined nearly all lakes and streams in the Sierra Nevada above 6000 feet were historically fishless. The stocking of fish in these areas may now increase the risk of mercury exposure to human and wildlife fish consumers.

Other commonly introduced fish species include rainbow trout, brown trout, catfish, bullhead, sunfish, and carp. All of these fish species bioaccumulate methylmercury, although to a lesser extent than black bass. Brown trout and older carp can bioaccumulate more, whereas rainbow trout are generally lowest in methylmercury. Rainbow trout are widely stocked and are a popular sport fish; many reservoirs must be continually stocked with rainbow trout to meet recreational demand (Pien 2014).

In summary, in addition to increasing the bioavailability and methylation of mercury, reservoir creation and introduced species increase the exposure of fish consumers to mercury by supporting a larger abundance and distribution of fish with higher mercury bioaccumulation rates. Yet continued restoration of anadromous fisheries, stocking fish with low mercury concentrations, and other fisheries management practices reviewed in Chapter 7 have the potential to reduce mercury exposure.

5 LINKAGE ANALYSIS

Overview

Chapter Objectives

This chapter presents a linkage analysis that establishes the quantitative relationships between fish methylmercury concentrations and environmental factors that control methylmercury production, bioaccumulation, and biomagnification in California reservoirs. The linkage analysis assesses more than 70 environmental factors identified by the conceptual model (Chapter 4) and includes statistical analyses and model development based on data collected from California reservoirs. The objectives of the linkage analysis are the following:

- Determine the factors that best predict fish methylmercury concentrations in California reservoirs.
- Determine the quantitative link between reservoir aqueous methylmercury concentrations and fish methylmercury concentrations to identify the aqueous methylmercury concentration necessary to achieve the sport fish target (0.2 milligrams per kilogram (mg/kg) in fish).
- Determine the quantitative link between reservoir sediment total mercury concentrations and fish methylmercury concentrations to identify the sediment total mercury concentration necessary to achieve the sport fish target.

The first section of this chapter summarizes the data collected from California reservoirs and their watersheds, and the statistical analyses and model development used to determine quantitative relationships between fish methylmercury concentrations and environmental factors. Appendix B provides a detailed description of the statistical methodologies and analyses. The remaining sections focus on the specific relationships between fish methylmercury concentrations, methylmercury concentrations in reservoir water (aqueous methylmercury), and inorganic mercury concentrations in reservoir sediments (sediment mercury).

Foundation from Previous Chapters

The conceptual model (Chapter 4) summarized an extensive literature review to describe mercury cycling in reservoirs and identify factors that affect fish methylmercury levels. The literature review identified a variety of reservoir and watershed factors that appear to affect mercury methylation and bioaccumulation in California and elsewhere. These factors form the scientific foundation of the linkage analysis presented in this chapter. A multiple-variable approach to the linkage analysis is appropriate given the (a) diversity of reservoir and watershed characteristics throughout the state as described in Chapters 2 and 4, and (b) magnitude of elevated fish methylmercury levels.

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Key Points from the Linkage Analysis

- The linkage analysis indicates that no single factor explains fish methylmercury concentrations in California reservoirs. Multiple factors drive reservoir fish methylmercury levels: amount of mercury, methylmercury production, and bioaccumulation.
- Important factors explaining fish methylmercury in California reservoirs include the following, in order of their importance: ratio of aqueous methylmercury to chlorophyll *a*; sediment total mercury concentration; longitude; watershed soil mercury concentration; annual reservoir water level fluctuation; chlorophyll *a* concentration; aqueous total mercury; and reservoir depth.
- The ratio of aqueous methylmercury to chlorophyll *a* explains 52% of the variability in fish methylmercury concentrations. Reservoir sediment mercury has the second strongest positive correlation and explains 24% of the variability. Both are statistically significant ($p < 10^{-4}$).
- Water Board staff evaluated a suite of multiple linear regression models to (a) determine the combination of factors that best predict fish methylmercury concentrations in California reservoirs, and (b) to identify the aqueous methylmercury concentration and sediment total mercury concentrations necessary to achieve the sport fish target of 0.2 mg/kg.
- When multiple factors are considered together, the ratio of aqueous methylmercury (AMeHg, ng/L) to chlorophyll *a* (Chl-a, µg/L), aqueous total mercury (ATHg, ng/L), and average of annual maxima reservoir water level fluctuations (AnnFluc) explain more variability in fish methylmercury concentrations than any other combination of factors. These three factors explain greater than 85% of the variability in reservoir fish methylmercury concentrations. The best model to predict methylmercury concentrations in California reservoir fish is:

$$\begin{aligned}\text{LN}^{1}[\text{Fish MeHg}] = &- 0.958 + 0.544\ ([\text{AMeHg}]/[\text{Chl-a}]\_\text{1-z}) + 0.271\ [\text{ATHg}]\_\text{1-z} \\ &+ 0.330\ (\text{AnnFluc})\_\text{1-z}\end{aligned}$$

Based on an evaluation of results from multiple models, staff recommends a goal of no detectable aqueous methylmercury (calendar year median, unfiltered, for the entire water column) at the detection limit of 0.009 ng/L to achieve the sport fish target. Although lower than the typical detection limit of 0.02 ng/L, the value is analytically feasible to achieve. Model results suggest that greater than 30% of reservoirs will require an aqueous methylmercury level lower than 0.009 ng/L if no other reservoir management actions are employed to achieve the sport fish target. Staff recommends re-evaluating the aqueous methylmercury goal in the future to determine whether a lower value is warranted (Chapter 9).

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[1] LN = Natural Log; units and data transformation (indicated by 1-z) are described in Appendix B

Overview, continued

- The model results indicate many reservoirs will require sediment mercury concentrations lower than both natural (pre-industrial) and modern (industrial-age) background concentrations to achieve the sport fish target. However, it is not feasible to reduce reservoir mercury concentrations to levels lower than background mercury concentrations. Consequently, staff proposes a goal for reservoir sediment total mercury concentrations to meet background watershed soil total mercury concentrations.
- The importance of the relationship between fish methylmercury concentrations and the ratio of aqueous methylmercury to chlorophyll *a* indicates that a successful mercury control program must either decrease aqueous methylmercury concentrations, increase primary production, or act on a combination of the two processes. The linkage analysis suggests making small increases in chlorophyll *a* concentrations could make substantial improvements or entirely resolve the mercury impairment in many oligotrophic reservoirs that currently have very low (≤3 µg Chl/L) chlorophyll *a* concentrations.

Implications

Most TMDL programs across the country focus on inorganic mercury source control to achieve fish methylmercury targets. This linkage analysis indicates that inorganic mercury sources are not the only factor explaining elevated fish methylmercury concentrations in California reservoirs. The linkage analysis indicates that many reservoirs will require very low inorganic mercury levels to achieve the sport fish target if the control program were to rely on source control alone. These findings have critical implications for the Statewide Mercury Control Program for Reservoirs:

- Mercury source control alone cannot achieve the sport fish target. Many reservoirs will require a combination of management practices including source control and reservoir water chemistry and fisheries management to reduce fish methylmercury concentrations to achieve the target. This program should include the identification and assessment of all potentially controllable processes that affect methylmercury production, degradation, and bioaccumulation. Chapter 7 in this report provides this assessment.
- Calculation of goals for total mercury source reduction should take into account technical feasibility to avoid having goals that are lower than natural background. Chapter 6 provides an assessment of mercury sources and Chapter 7 estimates how much these sources can be reduced.
- There is a large diversity of reservoir and watershed conditions throughout California. The implementation plan should be flexible enough to allow different combinations of management actions to account for and take advantage of that diversity.

5.1 Factors Controlling the Bioaccumulation of Methylmercury in California Reservoirs

This chapter presents a linkage analysis that establishes quantitative relationships between fish methylmercury concentrations and environmental factors that control methylmercury production, bioaccumulation, and biomagnification in California reservoirs. The linkage analysis assesses the relative importance of more than 70 factors identified by the conceptual model for methylmercury (Chapter 4) using statistical analyses of California data.

This section has five subsections. The first describes the environmental data used in the linkage analysis to characterize factors identified in Chapter 4. The other subsections describe correlations and quantitative relationships between individual factors and reservoir fish methylmercury, as well as the development of multiple linear regression models to predict reservoir fish methylmercury concentrations. Sections 5.2 through 5.4 use these models to predict the aqueous methylmercury, sediment total mercury, and aqueous chlorophyll *a* concentrations needed to achieve the sport fish target. Staff consulted with a University of California statistician to ensure that the analyses and conclusions presented in this chapter are robust. Finally, section 5.5 summarizes linkage analysis limitations and staff recommendations for next steps to address those limitations.

5.1.1 Environmental Data Used in the Linkage Analysis

Staff used a variety of environmental data for statistical model development:

- Reservoir data such as fish, water, sediment, soil total mercury and methylmercury, chlorophyll *a*, organic carbon, sulfate, and suspended sediment compiled from readily available reports and databases including California Environmental Data Exchange Network (CEDEN), Federal Energy Regulatory Commission (FERC) re-licensing studies, and other environmental studies (Appendix Z).
- Geographic Information System (GIS) analyses for reservoir spatial, morphological, and land use data.
- United States Environmental Protection Agency (USEPA) Regional Modeling System for Aerosols and Deposition (REMSAD) model (Chapter 6) for atmospheric mercury deposition to reservoirs.
- National Pollutant Discharge Elimination System (NPDES) permit information and California Integrated Water Quality System (CIWQS) for NPDES facility data (e.g., discharge volumes, mercury loading rates, number of discharges from each facility).

The linkage analysis assessed the influence of about 70 factors on fish methylmercury concentrations (Table 5.1 and Figure B.1). One hundred and twelve out of about 350 reservoirs with fish methylmercury data had sufficient information for use in the linkage analysis. Fish methylmercury concentrations in these reservoirs spanned from 0.02 to 4.2 mg/kg (350 mm standardized size; see Table B.1), from well below the sport fish target level of 0.2 mg/kg, to 21 times higher than the sport fish target.

Reservoirs assessed in the linkage analysis were not chosen using a random sampling design but instead were selected based upon the availability of data. In addition, data were not available for all factors identified in the conceptual model. Available data for all 74 reservoirs listed as mercury-impaired on the 2010 303(d) List were used in this analysis. Available data for another 38 reservoirs also were used. Insufficient information was available to assess the importance of dissolved organic carbon, pH, degree of anoxia, and food chain length. Evaluation of the linkage analysis results must consider these data limitations (see section 5.5).

The following sections are brief overviews of available data for the most important environmental factors; detailed information for the more than 70 factors evaluated is in Appendices B and Z.

Fish Data

As noted in Chapter 1, mercury is typically analyzed as “total mercury” in fish because of the additional cost required for methylmercury analysis. But mercury exists almost entirely in the methylated form in fish. Consequently, even though the fish mercury data presented in this chapter were generated by laboratory analyses for total mercury, the data are described as “methylmercury concentrations in fish.”

Fish methylmercury concentration data are available for 345 reservoirs and lakes throughout California (see Chapter 1 for a summary). More than half of these have at least 10 samples; however, nearly a third have only 1 or 2 samples (Table Z.1 in Appendix Z). About 80% of the fish methylmercury concentration data were collected since 2000, and more than half were collected in a three-year period, from 2006 to 2008. Of the 345 reservoirs and lakes, 267 (77%) have at least 2 samples collected during the 2006 – 2008 period.

Reservoir-specific fish methylmercury concentrations standardized for length and species were used in the linkage analysis, rather than average methylmercury concentrations. Standardization reduces variance in fish methylmercury concentrations caused by species- and site-specific bioaccumulation rates, and differences in distribution of sampled fish sizes resulting from differences in sample design and fish present at the time of sampling.

Methods similar to Tremblay and others (1998) and Davis and others (2010) were used to determine length-standardized fish methylmercury concentrations. The standardized fish for most reservoirs was 350 mm length largemouth bass (LMB). The 350 mm length was selected because it represents the middle of the typical size distribution caught for mercury analysis at most California reservoirs. A length of 350 mm also is above the recreational fishing legal size limit of 305 mm for largemouth bass in California. If no largemouth bass were available for a given reservoir, then other predatory fish data were used to calculate standardized fish methylmercury concentrations. Preference was given to smallmouth bass and spotted bass. If no predatory fish data were available, lower trophic level fish such as rainbow trout were used. Figure 5.1 identifies the reservoir-specific method for calculating length-standardized tissue concentrations and the species employed. Largemouth bass data were available for 78% of the 112 reservoirs, and other predatory fish were used in 19% of the reservoirs. Predatory fish data were not available for 3% of the 112 reservoirs, so rainbow trout, Sacramento sucker, or a combination of these two species was used.

In the final step of the linkage analysis, statistical models were used to predict fish methylmercury reductions associated with different types of potential implementation actions. The sport fish target is an average of 0.2 mg/kg in a legal-sized mixture of top trophic level fish ranging from 200 to 500 mm (see Chapter 3). However, the linkage analysis compares predicted standardized fish methylmercury concentrations to the target. An additional analysis was conducted to determine the difference between standardized fish methylmercury concentrations and average methylmercury concentrations in legal-sized trophic level four (TL4) fish (200 – 500 mm).

Figure 5.2 shows the correlation between standardized fish methylmercury concentrations and the average concentrations in legal-sized top trophic level fish (length 200 – 500 mm TL4 or 150 – 500 mm TL3). The relationship is:

LN [Standardized fish Hg] = -0.2321 + 0.8248 * LN(Average Hg in legal-sized top trophic fish)

R^2 = 0.82, n = 107 reservoirs

An average methylmercury concentration of 0.2 mg/kg in legal-sized TL4 fish equates to virtually the same concentration in standardized fish methylmercury. Consequently, later in this chapter the sport fish target of 0.2 mg/kg is compared directly to model-predicted standardized fish methylmercury concentrations without adjustment.

An average methylmercury concentration of 0.2 mg/kg in legal-sized TL4 fish is equivalent to 0.21 mg/kg in standardized fish. The two values are almost identical, which confirms the robustness of using standardized fish methylmercury concentrations for assessing compliance with the sport fish target.

As described more in Appendix B, this is a conservative comparison and incorporates an implicit margin of safety. The sport fish target applies to top trophic level species, while the fish data used to calculate average 150 – 500 mm (legal catch) top trophic level fish methylmercury concentrations for the linkage analysis are dominated by largemouth bass and other black bass (smallmouth and spotted bass). Black bass typically bioaccumulate more methylmercury than more commonly consumed TL4 species such as catfish.

A linkage analysis based primarily on standardized fish methylmercury is a valid approach for TMDL calculations such as assimilative capacity and allocations. This approach has been used for mercury TMDLs developed elsewhere in the state (e.g., the Sacramento-San Joaquin River Delta and reservoirs in the Los Angeles region; Wood et al. 2010a and 2010b; USEPA 2012e). In addition, this is a conservative approach for reservoirs that do not have black bass because black bass typically bioaccumulate the highest levels of methylmercury. Thus, these TMDL calculations should also be protective of reservoirs that do not have black bass.

Water Data

Concentration data for each reservoir were summarized using geometric means if the data did not contain non-detect values.[2] Appendix B describes the summary methods used for data with non-detect values.

Aqueous methylmercury concentration data are available for 53 reservoirs, though generally there are few measurements for each site. Much more information is available for near-surface, unfiltered water samples than for lower (hypolimnion) in the water column or for filtered samples. Consequently, the linkage analysis uses results for unfiltered samples collected throughout the water column and throughout the year. Methylmercury is largely accumulated in surface waters (epilimnion), even though, as described in the conceptual model, much of it is initially formed in sediments and discharged into the hypolimnion. Methylmercury may accumulate to very high levels in the hypolimnion, as, for example, in Davis Creek Reservoir (Slotton et al. 1997) and reservoirs in the Guadalupe River watershed when they were thermally stratified (Tetra Tech 2005b). This methylmercury bioaccumulates in the food chain at fall overturn when deep waters mix with shallow surface water.

Aqueous total mercury concentration data for unfiltered water samples are available for 47 reservoirs.

Other Reservoir Data

Sediment total mercury concentration data are available for 62 reservoirs; 43 reservoirs have only 1 or 2 samples, and the remaining have between 3 and 98 samples. Soil total mercury concentration is for upland watershed soils. Soil data was available for 59 reservoirs. These samples are thought to represent *modern* background soil concentrations.

Annual water level fluctuation is the water year reservoir maximum elevation minus the water year minimum elevation. The average annual water level fluctuation is the mean of available years of data. Elevation data were available for 65 reservoirs. The number of years used to calculate the average ranged from 1 to about 25 years.

Reservoir latitude (north – south), longitude (east – west), dam height (a proxy for reservoir depth), and dam elevation data were compiled from readily available reports and databases. Land use data (e.g., historic mine density, percent forests, and surface area) were determined from GIS analysis. Atmospheric deposition rates were determined from the USEPA's REMSAD model (see Chapter 6, Source Assessment). NPDES-permitted facility data were compiled from permit project files, CIWQS, and GIS analyses.

Data Transformations and Statistical Significance

As described in Appendix B, Box-Cox Power transformations were performed on all data to meet assumptions of parametric statistics. Some data did not meet the assumptions of normality

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[2] The geometric mean (geomean) is the n-th root of the product of n numbers. Alternatively, the geometric mean can be calculated by averaging the base 10 or natural logarithmic values of a data set, and then calculating the antilog of the resulting average.

even after transformation, so nonparametric statistical analyses also were performed. In addition, for use in the multivariable models, variables were z-score standardized (mean centered and divided by the standard deviation) to give variables equal weights. Analyses resulting in p-values less than 0.05 were considered statistically significant.

5.1.2 Correlations Between Environmental Factors and Fish Methylmercury

Parametric (Pearson's r) and non-parametric (Spearman's rho and Kendall's tau) correlation coefficients and their two-sided test of significance were calculated for each variable (environmental factor) to determine which are correlated with reservoir fish methylmercury concentrations (Table B.3 in Appendix B). Correlations do not imply a cause and effect relationship; however, causation may be inferred, when supported by known biological, chemical, or physical processes.

For the most part, the parametric and nonparametric results agreed on the relative strength of associations (Table B.3). Pearson's correlation (*r*) results are used here unless there are discrepancies in results between the parametric and non-parametric methods. The absolute value of some correlation coefficients is displayed in the text because some variables (e.g., aqueous methylmercury and chlorophyll) were inversely transformed, and for these a negative correlation coefficient would represent positive associations (i.e., both variables increase together when not transformed).

Fish methylmercury concentrations were most strongly correlated ($r = 0.72$, $p < 10^{-7}$) with the ratio of unfiltered aqueous methylmercury to chlorophyll *a* concentration (Table B.3). The ratio represents biodilution: the amount of methylmercury entering the base of the food web and available for biomagnification divided by the amount of carbon available for tissue growth. See Chapter 4 and Appendix A for a detailed literature review about the relationship between primary productivity and fish methylmercury concentrations.

Fish methylmercury concentrations also were correlated ($p < 0.05$) with other environmental factors (Table B.3), including the following in order of the strength of their associations: sediment total mercury concentration; longitude; watershed soil mercury concentration; annual reservoir water level fluctuation; chlorophyll *a* concentration; aqueous total mercury; and reservoir depth.

Fish methylmercury concentrations were not correlated ($p > 0.05$) with several other mercury source types: municipal and industrial facilities; urban runoff from medium and high density developed areas; watershed mine density; and upstream wetlands (Table B.3). The lack of a correlation with fish methylmercury suggests that methylmercury bioaccumulation in the food web is dominated by in-reservoir methylmercury production processes more than by upstream methylmercury influx.

As previously stated, fish methylmercury concentrations were strongly correlated with concentrations of total mercury and methylmercury in water and sediment (Table B.3), as expected from the literature review. Likewise, the various forms of mercury concentrations in reservoirs were correlated with each other (Table B.4 in Appendix B), suggesting internal cycling of mercury within the reservoirs ($|r| = 0.38 – 0.70$) (e.g., more inorganic mercury is associated with more methylmercury). This supports the literature review finding that the magnitude of inorganic mercury contamination is important in determining fish methylmercury levels, and that reductions in aqueous and sediment inorganic mercury will result in reductions in fish methylmercury concentrations.

Aqueous methylmercury and sediment total mercury in reservoirs were positively associated with several upstream sources of mercury ($|r| = 0.30 – 0.51$), e.g., watershed soil mercury concentrations and atmospheric deposition mercury loading rates (Table B.4). Additionally, aqueous total mercury was positively associated with watershed soil mercury concentrations ($r = 0.40$, $p < 0.05$). To a lesser extent, the magnitude of mercury sources were positively correlated to standardized fish methylmercury concentrations. These include the total mercury atmospheric loads grams per year (g/year) to a reservoir's surface from California emission sources
($r = 0.2$, $p < 0.05$).

These positive associations further reinforce the importance of the magnitude of total mercury sources in controlling fish methylmercury concentration; however, the weakness of the associations, compared to other environmental factors, suggests there may be other processes with a more direct and important influence on methylmercury bioaccumulation in fish. (See Chapter 7 for a comparison of upstream mine density and number of productive mines in watershed to reservoir bottom sediment mercury concentration.)

The correlation results in Tables B.3 and B.4 suggest that a combination of factors influence fish methylmercury concentrations, and that a multiple-variable analysis is required to explain more of the variability in reservoir fish methylmercury concentrations. Consequently, all variables with statistically significant associations with fish methylmercury were evaluated using a multivariate approach to determine if a suite of variables might be more predictive of fish methylmercury concentrations than any single factor, as described in the next section.

5.1.3 Multiple Linear Regression Models to Predict Reservoir Fish Methylmercury

Seventeen variables were evaluated in a suite of multiple linear regression models to determine their influence on fish methylmercury concentrations. As described in Appendix B, best subsets regression was used to determine the combination of factors that explained the greatest amount of variability in fish methylmercury. The overall measures of quality (Mallow's Cp, PRESS, and adjusted R^2) of the models were used to determine the best models.

Best Model

The best subsets regression analysis produced several statistically significant models that explained differing amounts of variability in fish methylmercury. The best model (Model 1) to predict methylmercury concentrations in California reservoir fish is:

LN [Fish MeHg] = - 0.958 + 0.544 (Ratio [MeHg]/[Chl-a]_1-z) + 0.271 [Aqueous THg]_1-z + 0.330 (AnnFluc)_1-z

Adjusted $R^2 = 0.84$, $p < 0.001$, $n = 26$ reservoirs

Where:

Fish MeHg: Length-standardized methylmercury concentration (mg/kg) in highest tropic level fish (typically 350 mm bass)
AMeHg: Aqueous methylmercury concentration (ng/L)
Chl-a: Chlorophyll a concentration (μg/L)
ATHg: Aqueous total mercury concentration (ng/L)
AnnFluc: Average of annual maximum reservoir water level fluctuation (feet)

As described in Appendix B, the aqueous total mercury (THg), reservoir water level fluctuations, and ratios of aqueous methylmercury to chlorophyll *a* ([*MeHg]/[Chl-a]*) were transformed and z-score standardized, as indicated by "LN," "_1," and "-z."

Model 1 explains the greatest amount of variability in reservoir fish methylmercury concentrations. The high R^2 value indicates that Model 1 produces minimal error when predicting fish concentrations in the reservoirs used to develop it. These reservoirs had a wide range of fish methylmercury concentrations, sediment mercury concentrations, sizes, locations, chlorophyll *a* concentrations, atmospheric deposition amounts, and watershed mining densities (Table 5.1 and Appendix B). Consequently, Model 1 may be applicable for describing important factors driving fish methylmercury levels in both reservoirs used to develop the model and other reservoirs that may be identified as mercury impaired in the future.

Other statistically significant ($R^2 = 0.6 – 0.8$) models also were identified. Independent variables that were good predictors of fish methylmercury in these multiple linear regression models include: sediment total mercury, watershed area and percent vegetation, elevation, aqueous methylmercury, and chlorophyll *a* without the use of a ratio (see Tables 5.2 and 5.5). Several of these models are considered in the following sections because they are useful for predicting fish methylmercury reductions associated with potential implementation actions.

Mechanisms

The mechanisms by which the different variables influence fish methylmercury concentrations are explained in detail in the conceptual model (Chapter 4) and in Appendix A. The following is a brief review.

Aqueous total mercury concentration. Methylmercury is produced by the methylation of inorganic mercury. In laboratory experiments, positive correlations have been observed between total mercury and methylmercury in the environment. The total mercury in the aquatic environment primarily is comprised of inorganic mercury, so increasing the amount of total mercury in the water column of a reservoir will likely result in higher methylmercury concentrations. Incoming inorganic mercury, which is primarily particulate bound, settles to the bottom of reservoirs where it can become methylated.

Ratio of aqueous methylmercury to chlorophyll. Biomagnification of methylmercury in aquatic ecosystems is a dietary phenomenon, and the ratio of methylmercury to chlorophyll represents the magnitude of methylmercury entering the food web through pelagic primary production. Production of methylmercury and algae are largely independent processes. Therefore, an increase in algal biomass results in a decrease in the concentration of methylmercury per gram of algal material, resulting in a lower dietary input to grazers and reduced methylmercury concentrations in the grazers (Pickhardt et al. 2002). This process is called algal bloom dilution (Appendix A).

Likewise, abundance of algae affects the growth rate of organisms feeding on algae. Through somatic growth dilution, greater availability of food allows an organism or population growth rate to increase faster than methylmercury is assimilated, and result in a lower methylmercury concentration in their tissue.

Model 1 and other statistically significant multiple linear regression models (Appendix B) included reservoir chlorophyll *a* concentration as a negatively correlated predictor variable, either independently or as a ratio with aqueous methylmercury. This indicates that the amount of chlorophyll *a* is likely an important environmental factor in predicting reservoir fish methylmercury concentrations.

<u>Annual water level fluctuation</u>. The magnitude of reservoir water level fluctuation may act upon multiple pathways of mercury cycling. First, the drying and rewetting of soils has been shown to stimulate methylation through the oxidation of dried soils. As reservoirs fill, rewetted soils can become anoxic which can result in a drop in redox potential. The resulting anoxia and reducing conditions can result in the increase of sulfate-reduction and methylmercury production. However, in California reservoirs there was a negative weak (not statistically significant) relationship between aqueous methylmercury and annual water level fluctuations, which suggests that water level fluctuations do not increase aqueous methylmercury concentrations.

Model 1 and several other statistically significant regression models (Appendix B) included annual water level fluctuation as a positively correlated predictor variable for fish methylmercury concentrations. As discussed in Appendix A, the large fluctuations in reservoirs erode their banks of fine grain material and nutrients. The loss of benthic sediment and nutrients reduces benthic primary production. Benthic primary production can be as important as pelagic primary production in providing food for aquatic biota. The result is an increase in fish methylmercury concentrations through the reverse of somatic growth dilution.

Although large reservoir water level fluctuations have been associated with increased fish methylmercury levels in California and elsewhere, staff recommends the implementation plan not include muting water level fluctuations as an implementation option for reducing reservoir fish methylmercury levels. Most California reservoirs are designed to empty and re-fill annually. Staff recommends that the implementation plan respond to the effects of water level fluctuations rather than require changes in reservoir water level operations in recognition of the fundamental property that reservoir water levels decrease during California's long dry season. Consequently, water level fluctuations are not further evaluated.

5.2 Relationship between Aqueous Methylmercury and Fish Methylmercury, and Calculation of Aqueous Methylmercury Goal

Methylmercury is the primary form of mercury that is bioaccumulated in fish and poses the greatest risk of toxicological effects. Aqueous methylmercury concentration is the key factor in determining biota methylmercury concentrations (Morel 1998). Chapter 4 gave examples where statistically significant, positive correlations were observed between aqueous and fish methylmercury concentrations in many different water body types (e.g., rivers, lakes, and reservoirs). The current analyses observe this relationship in California reservoirs, too (Table B.3 in Appendix B).

Staff predicts that reducing aqueous methylmercury concentrations will result in reductions in fish methylmercury in California reservoirs. Staff evaluated two methods for calculating a methylmercury concentration in reservoir water to achieve the sport fish target: regression models and bioaccumulation factors (BAFs).

5.2.1 Regressions for Aqueous Methylmercury Versus Fish Methylmercury

Regressions of aqueous methylmercury to fish methylmercury were used to predict aqueous methylmercury concentrations needed to attain the sport fish target. This method is considered a more accurate predictor of necessary aqueous methylmercury reductions than the BAF method described in the next section.

Staff used several multiple linear regression models to predict reservoir fish methylmercury concentrations that can be rearranged to predict the aqueous methylmercury concentrations needed to attain the 0.2 mg/kg sport fish target (Appendix B). Table 5.2 summarizes key features of these models and Appendix B provides additional explanation.

The best model (Model 1) to predict methylmercury concentrations in California reservoir fish described in the previous section includes aqueous methylmercury as a ratio with chlorophyll. Model 1 is statistically significant ($p < 0.001$) and has an R^2 (adjusted) of 84%. Model 1 may not be statistically appropriate to evaluate aqueous methylmercury as a variable separate from chlorophyll *a* because Model 1 assessed aqueous methylmercury as a ratio with chlorophyll.

Consequently, staff evaluated two additional models, Models 2 and 3 (Tables 5.2 and 5.3). Both were developed using best subsets regression and, although they have lower adjusted R^2 values than Model 1 (59% and 55%, compared to 84%), they are statistically significant ($p <$ 0.001) and have two advantages. Firstly, Models 2 and 3 assess aqueous methylmercury and chlorophyll *a* without the use of their ratio. In addition, they include more reservoirs in their development: 35 and 43 reservoirs for Models 2 and 3 respectively, compared to 26 reservoirs for Model 1.

Staff used Models 2 and 3 to predict the aqueous methylmercury concentrations needed to achieve the sport fish target. This analysis assumes that other variables such as chlorophyll *a* and aqueous total mercury concentrations do not change. These predicted aqueous methylmercury concentrations are referred to as “predicted reservoir-specific AMeHg goals”. The predicted reservoir-specific AMeHg goals vary by model because the models include different combinations of reservoir and watershed factors. Use of multiple models is important as they provide a range of water goals for each reservoir and illustrate the uncertainty in the predicted values.

The medians of reservoir-specific AMeHg goals for Models 2 and 3 are 0.01 and 0.02 ng/L, respectively (Table 5.2). The currently practiced method detection limit (MDL) for methylmercury in water is 0.02 ng/L (USEPA Method 1630). The models predict that a statewide AMeHg goal of 0.02 ng/L would be protective of less than half of the impaired reservoirs. See Appendix B for additional review of reservoir-specific predictions.

USEPA Method 1630 states that an MDL of 0.009 ng/L for methylmercury in water should be analytically achievable, if a laboratory uses “extra caution in sample handling and reagent selection, particularly the use of ‘for ultra-low level only’ distillation equipment” (USEPA 1998). Models 2 and 3 predict that a statewide AMeHg goal of 0.009 ng/L may result in about 70% of reservoirs meeting the sport fish target (Table 5.3). The fish mercury impairment in the remaining reservoirs with aqueous methylmercury greater than 0.009 ng/L would be reduced by more than half if this goal were achieved (Table 5.3).

Many of the California reservoirs with elevated fish methylmercury levels have frequent measurements of aqueous methylmercury below the MDL of 0.02 ng/L. The current MDL is not adequate to reliably measure environmental concentrations of methylmercury in these water bodies. The Central Valley Water Board contracted with the Department of Fish and Wildlife, Marine Pollution Studies Laboratory, to conduct a study to determine if it was possible to analyze aqueous methylmercury with an MDL lower than 0.02 ng/L. The laboratory was successful at lowering the MDL for methylmercury in water down to 0.005 ng/L (Byington 2012).

Models 2 and 3 predict that a statewide AMeHg goal of 0.005 ng/L may be protective of all, or nearly all, reservoirs (Table 5.2). A lower MDL also would allow researchers to better understand relationships between mercury control actions and aqueous methylmercury reductions, and between aqueous methylmercury reductions and fish methylmercury reductions.

5.2.2 Aqueous Bioaccumulation Factor (BAF) Evaluation

An aqueous bioaccumulation factor evaluation is the second method used to predict aqueous methylmercury concentrations that will attain the sport fish target. An aqueous BAF is the ratio of a chemical in fish tissue to the concentration in the water (USEPA 2001a). BAFs are intended to describe the bioaccumulation of a chemical through dietary intake and not through absorption from water or bioconcentration. BAFs are an accepted national method to describe the relationship between pollutant concentrations in fish and water. The equation to calculate a water body’s BAF is:

BAF = [Fish MeHg] / [Aqueous MeHg]

USEPA (2001a) recommends using the national default BAF (1.7 x 10^6 (liters per kilogram (L/kg)) for TL4 fish, adjusted for total methylmercury in water) where no site-specific data are available. If local or regional data is available, USEPA recommends developing methylmercury BAFs using those sources (USEPA 2001a).

BAFs for 51 California reservoirs were calculated (Table 5.4). BAFs ranged from 0.7 x 10^6 to 75 x 10^6 (L/kg) for legal-sized TL4 fish, and from 11 x 10^6 to 110 x 10^6 (L/kg) for length-standardized TL4 fish. The geometric mean BAF for average and standardized TL4 fish was 11 x 10^6 and 12 x 10^6 (L/kg), respectively. California reservoirs appear to have higher rates of methylmercury bioaccumulation than water bodies used in the national default BAF.

A known problem with the BAF methodology is that it does not incorporate other factors in the bioaccumulation prediction. The use of BAFs assumes a 1:1 linear relationship between fish methylmercury and aqueous methylmercury. The multiple regression approach demonstrates the importance of other factors for California reservoirs. This limitation was recognized in the development of the national default BAF (USEPA 2001a). USEPA recommended that other methods be used where available. Staff recommends the multiple linear regression equations be used to predict a statewide aqueous methylmercury goal to attain the sport fish target.

5.2.3 Statewide Aqueous Methylmercury Goal

The calculated statewide aqueous methylmercury goal is the estimated maximum long-term concentration in the entire water column needed to attain the sport fish target in California reservoirs, but it is constrained by feasibility as described herein. Statistically significant positive correlations were observed in California reservoirs between aqueous methylmercury concentrations and fish methylmercury concentration. The correlations, linkage analysis, and conceptual model indicate that fish methylmercury levels in California reservoirs can be reduced, in part, by reducing aqueous methylmercury concentrations.

To meet the sport fish target, staff recommends a statewide goal of no detectable aqueous methylmercury in unfiltered reservoir water (calendar year median for the entire water column, including the epilimnion and hypolimnion) at the detection limit of 0.009 ng/L. This goal is based on the following considerations: (1) the data set is comprised of geometric mean and median aqueous methylmercury for the entire water column and throughout the calendar year (see Appendix B); (2) calculations using the multiple linear regression equations (in section 5.2.1); (3) the MDL for aqueous methylmercury is technically feasible as described by the USEPA Method 1630; (4) calendar year represents long-term bioaccumulation; (5) calendar year accounts for differences in methylmercury production resulting from annual hydrologic variation in reservoirs; and (6) median provides an estimate of central tendency and unlike geometric mean can be calculated with non-detect values (i.e., concentrations below the analytical method detection limits). This goal will be used to determine assimilative capacity and allocations (Chapters 7, 8, and 9).

The regression models predict that 25 – 40% of reservoirs may require methylmercury concentrations below 0.009 ng/L to attain the sport fish target. It is not currently feasible for most analytical laboratories to measure below 0.009 ng/L. As a result, the goal will default to 0.009 ng/L, the minimum aqueous methylmercury concentration that USEPA Method 1630 states should be feasible (USEPA 1998). Staff recommends that the implementation plan incorporate an adaptive management approach that allows the goal to be re-evaluated after more data are collected. In addition, methylmercury in water is only one of several factors controlling fish methylmercury concentration. It is likely that multiple actions (e.g., source controls, water chemistry and fisheries management changes) could be—and will need to be—implemented to achieve the sport fish target. The implementation plan should incorporate a flexible design that encourages adaptive management and a variety of implementation actions to reduce reservoir fish methylmercury levels.

5.3 Relationship Between Sediment Mercury and Fish Methylmercury, and Calculation of Sediment Total Mercury Goal

Sediment total mercury concentrations have been positively correlated to fish and aqueous methylmercury concentrations in a variety of water body types elsewhere. Both relationships have been confirmed for California reservoirs (Table 5.5 and Tables B.3 and B.4 in Appendix B). These relationships indicate that a reduction in reservoir sediment mercury concentrations will result in a reduction in methylmercury production and bioaccumulation in fish in California reservoirs. Statistical models that include sediment mercury concentration are considered in this section because they are useful for predicting fish methylmercury reductions resulting from potential implementation actions.

5.3.1 Regressions for Fish Methylmercury Versus Sediment Mercury

Regressions of sediment total mercury to fish methylmercury are the first method used to predict sediment total mercury concentrations needed to attain the sport fish target. This method is considered a more accurate predictor of sediment total mercury concentrations needed to achieve the sport fish target than the Biota-sediment accumulation factor (BSAF) method described in the next section.

Staff used two regression models (Models A and B) to predict the reservoir sediment total mercury concentrations necessary to attain the 0.2 mg/kg sport fish target. This approach is similar to the method previously described for aqueous methylmercury. This analysis assumes that all other variables remain constant. Table 5.5 summarizes key features of these models; Appendix B provides additional explanation.

The predicted sediment total mercury concentrations are referred to as “predicted reservoir-specific STHg goals.” The predicted reservoir-specific STHg goals are model-specific because Model A is based on data for 50 reservoirs and several watershed factors while Model B is based on data for 62 reservoirs but includes only one factor (reservoir sediment total mercury).

Model A predicts a range of reservoir-specific STHg goals with median and lower 1st percentile values of 0.02 mg/kg and 0.002 mg/kg, respectively. Model B predicts a single STHg goal—0.02 mg/kg—for all 62 reservoirs.

The lower 1st percentile of the reservoir-specific STHg goals predicted by Model A—0.002 mg/kg— is the lowest observed natural geologic background value for California soils (see Chapter 6). It is one to two orders of magnitude lower than natural background levels in the Coast Ranges. The linkage analysis suggests that many reservoirs will need sediment mercury concentrations lower than the natural background in their watersheds to achieve the sport fish target. Reducing sediment concentrations below a watershed’s natural background level is not feasible and is not recommended as a sediment mercury goal.

Indeed, many impaired reservoirs included in model development already have sediment mercury concentrations within natural background levels (Figure 5.3), which indicates that reservoirs can have elevated fish methylmercury even though sediment mercury levels are very low (Table 5.6). Further, there is substantial fish methylmercury variability not explained by sediment THg concentrations. There can be high fish methylmercury in reservoirs where there is low sediment mercury, low fish methylmercury where there is high sediment mercury, and reservoirs where there is extensive mercury contamination but the fish methylmercury are not as high as expected from the high sediment mercury concentrations (Figure 5.3). Multiple factors are at play, more than just mercury pollution sources and associated sediment mercury concentrations.

Models A and B predict that only about 5% of mercury-impaired reservoirs will completely correct their fish mercury impairments by reducing sediment concentrations to natural background levels (Table 5.6). Even so, control actions that reduce sediment mercury concentrations are expected to result in substantial reductions in fish methylmercury even if they do not entirely solve the impairment. By reducing sediment concentrations to natural background levels, Models A and B predict that 39% and 44% of impaired reservoirs will correct 25 – 50% of their fish mercury impairment, respectively. These predictions emphasize the need for multiple control actions, not only source control, to achieve the sport fish target.

5.3.2 Biota-Sediment Accumulation Factor (BSAF) Evaluation

BSAF evaluation is the second method used to predict sediment methylmercury concentrations to attain the sport fish target; this method is not considered as robust as the regression approach described in the previous section.

Similar to aqueous BAF, the BSAF is the ratio of a chemical in fish tissue to the concentration in sediment. The method used in the evaluation of reservoir data is modified from other commonly used methods for evaluating biota–sediment accumulation factors (Burkhard 2009). These other methods normalize the contaminant to fish lipid content and sediment carbon content. Neither fish lipid levels nor the carbon content of the sediment were available for California reservoirs. Without these other influencing factors, the BSAF assumes a 1:1 linear relationship between fish methylmercury and sediment total mercury; however, the previous section indicates this relationship is not true for California reservoirs. Thus, the regression methods in the previous section better predict the sediment total mercury concentrations that will attain the sport fish target.

5.3.3 Sediment Total Mercury Goal

The calculated sediment total mercury goal is the estimated maximum (geomean) total mercury concentration in reservoir bottom sediment needed to attain the sport fish target in California reservoirs, but it is constrained by feasibility as described herein. Statistically significant positive correlations were observed in California reservoirs between sediment total mercury concentrations and fish methylmercury concentration. The correlations, linkage analysis, and conceptual model indicate that fish methylmercury levels in California reservoirs can be reduced, in part, by reducing sediment total mercury concentration.

To attain the sport fish target, staff recommends a reservoir sediment total mercury goal (geometric mean) equal to modern background total mercury concentrations for the regional native soil type (see Chapters 6 and 7). This goal is based on several considerations. First, the predicted reservoir-specific sediment total mercury concentrations to meet the sport fish target using Models A and B require total mercury concentrations lower than natural (pre-industrial) background in most locations. This is not a feasible goal. Also, as discussed in Chapters 6 and 7, modern (industrial era) background soil mercury levels are elevated above natural background because mercury emissions and atmospheric deposition have increased soil mercury concentrations since the beginning of the industrial era. It could take decades to centuries for industrial-era mercury in watershed soils and sediments to be depleted.

Approximately 40% of the impaired reservoirs have sediment total mercury concentrations that are comparable to modern and natural background concentrations, and there are very few reservoirs where mercury source control actions are expected to make rapid reductions in reservoir fish methylmercury levels (Chapters 6 and 7). Staff recommends that the implementation plan incorporate realistic expectations for source reductions and associated TMDL allocations for inorganic mercury sources.

Like aqueous methylmercury concentrations, sediment total mercury concentrations are not the only limiting factor in determining fish methylmercury concentrations in reservoirs. Control of other mercury cycling factors, in addition to source control, will be necessary for most reservoirs to achieve the sport fish target.

Model predictions described in Appendix B indicate a reduction of sediment total mercury concentrations to near zero anthropogenic inputs, in conjunction with meeting the aqueous methylmercury goal of 0.009 ng/L, will achieve the sport fish target in California's impaired reservoirs. However, there are many reservoirs where reducing sediment mercury alone is not expected to make substantial fish methylmercury reductions because sediment mercury levels are already at background levels. Attaining the sport fish target at these reservoirs likely will require implementing reservoir water chemistry management practices to reduce aqueous methylmercury concentrations and/or fisheries management practices to reduce methylmercury bioaccumulation in the food web.

For example, as described in the next section and Appendix A, nutrient additions in strongly oligotrophic reservoirs could be an effective means of reducing fish methylmercury levels. Staff recommends that the implementation plan allow and encourage a variety of actions to reduce reservoir fish methylmercury levels, and incorporate an adaptive management approach that allows the sediment total mercury and aqueous methylmercury goals to be re-evaluated after more data and information are collected.

5.4 Relationship between Chlorophyll *a* and Fish Methylmercury

The ratio of unfiltered aqueous methylmercury to chlorophyll *a* explained the largest amount of variation in standardized fish methylmercury concentrations of any single variable evaluated for California reservoirs ($r = 0.72$, $p < 10^{-7}$, section 5.1 and Appendix B Table B.3). The ratio represents biodilution: the amount of methylmercury entering the base of the food web and available for biomagnification divided by the amount of carbon available for tissue growth. Further, Models 1 – 3 included reservoir chlorophyll *a* concentration as a negatively correlated predictor variable, either independently or as a ratio with aqueous methylmercury. These relationships suggest that, where reservoir chlorophyll *a* levels are currently very low, an increase in chlorophyll *a* levels would reduce methylmercury bioaccumulation in fish in California reservoirs.

The linkage analysis establishes the relationship between chlorophyll and aqueous methylmercury in aquatic ecosystems. Implementation measures to achieve the sport fish target by managing chlorophyll concentrations are summarized below. Additional implementation strategies are detailed in Chapter 9.

Appendix A provides a detailed review of the mechanisms whereby chlorophyll and primary production control the accumulation and transfer of methylmercury in aquatic food webs. In addition, Appendix A provides the following:

- A review of the phenomenon of cultural oligotrophication with descriptions of how oligotrophication decreases nutrient concentrations, resulting in reductions in primary and secondary production, decreases in fish yield, and likely increases in biotic methylmercury levels.
- Results of and lessons learned from decades of nutrient fertilization programs in lakes and rivers elsewhere to reverse cultural oligotrophication and restore economically important commercial and recreational fisheries. These results may be of interest to the State of California and reservoir operators should they decide to consider fertilization as a temporary implementation option for reducing fish methylmercury levels while longer term mercury control measures are implemented.
- Estimates of the amount of additional chlorophyll needed from a fertilization program to reduce fish methylmercury concentrations to attain the sport fish target in California reservoirs.
- A review of the California Nutrient Criteria Program currently under development and how it is unlikely to negatively affect the implementation of a fertilization program designed to reduce biota methylmercury levels.

The Canadian Department of Fisheries and Oceans has several decades of experience in fertilizing over 20 British Columbia reservoirs created to generate hydroelectric power. Lake researchers provide the following guidelines based on this experience (Stockner and MacIssac 1996):

- Oligotrophic lakes with summer epilimnetic chlorophyll concentrations less than 3 µg Chl/L are candidates for fertilization. Such oligotrophic water bodies were sufficiently nutrient poor to consistently respond in a positive “bottom up” fashion to the addition of small amounts of N and P.
- A fertilization program should not attempt to alter the basic oligotrophic character of a water body. This includes changes in algal species composition, hypolimnetic dissolved oxygen concentrations, or water column secchi depth. To ensure this, fertilization should not increase ambient summer chlorophyll levels more than twofold.
- A fertilization program should not alter algal species composition. This can be achieved by managing the ratio of N : P in the fertilizer.
- A fertilization program should only be considered a temporary solution until a permanent fix can be devised.

The effect of light fertilization is reversible. All British Columbia reservoirs returned to their original nutrient status several years after fertilization ceased.

Predictions for Light Fertilization in Oligotrophic Reservoirs in California

Several mercury-impaired reservoirs in California are potential candidates for fertilization trials. Of the 49 reservoirs with chlorophyll data (Table B.1 Appendix B), 35 (~70%) have standardized fish methylmercury concentrations that exceed the sport fish target (0.2 mg/kg). Of these 35 water bodies, 21 have geometric mean chlorophyll *a* concentrations at or below 3 µg Chl/L. This makes them potential candidates for fertilization. It also suggests that their oligotrophic nature may contribute to their fish methylmercury problem as would be predicted from algal bloom and somatic growth dilution. Candidate lakes are widely distributed geographically across the State. They include water bodies from the Coast Range, Trinity Alps, low and high elevations in the Sierra Nevada, and Southern California.

Staff used Models 2 and 3 to assess whether a reservoir nutrient fertilization program might help reduce fish methylmercury concentrations in the mercury-impaired reservoirs with geometric mean chlorophyll *a* concentrations at or below 3 µg Chl/L. This approach is similar to the method previously described for aqueous methylmercury in section 5.2. This analysis assumes that all variables other than chlorophyll *a* remain constant. Table 5.3 summarizes key features of Models 2 and 3 and Appendix B provides additional explanation. The analysis is based on water bodies with environmental data presented in Table B.1 in Appendix B. Many of the geometric mean chlorophyll *a* concentrations should be considered preliminary as some values are not based on many measurements. As such, the predictions from this analysis should be considered preliminary until a more comprehensive chlorophyll data set is collected.

Table A.1 in Appendix A summarizes predictions from both models for the percent reduction in the fish mercury impairment if chlorophyll concentrations were doubled. Model 3 predicts that doubling chlorophyll would completely resolve the mercury impairment in 46% of reservoirs where chlorophyll levels do not exceed 3 µg/L and would reduce the impairment by half in the remaining reservoirs. In contrast, Model 2 predicts that no reservoir would be completely corrected by doubling chlorophyll concentrations, 19% of reservoirs would have their fish mercury impairment reduced by at least 50%, and all would show at least a 25% reduction in their impairment.

These model predictions indicate that implementing a light fertilization program could make substantial improvements or entirely fix the mercury impairment in many oligotrophic reservoirs. However, while implementing a light fertilization program appears promising, the different model predictions emphasize the need for controlled, whole-reservoir studies to determine the efficacy, practicality, and cost of nutrient additions to reduce mercury impairments.

Based on these results, staff recommends that the implementation plan include reservoir pilot tests that could include experimental nutrient fertilization studies in representative reservoirs to determine the feasibility of using nutrient additions to reduce fish methylmercury concentrations. The studies also should document the unintended negative consequences of nutrient additions.

5.5 Linkage Analysis Limitations and Recommendations

Staff identified several linkage analysis limitations throughout this chapter and Appendix B. First, reservoirs assessed in the linkage analyses were not chosen using a random sampling design but instead were selected based upon the availability of data. As described in Appendix B, the reservoirs incorporated in the linkage models have similar fish methylmercury concentrations and distributions as the reservoirs that are of concern for this control program—reservoirs with elevated fish methylmercury levels—but may not be representative of reservoirs with low fish methylmercury levels. Additional data are not expected to change the overall conclusions about the most important factors influencing methylmercury accumulation in fish in mercury-impaired reservoirs. Nevertheless, the collection of additional data for reservoirs with low fish methylmercury concentrations may lead to the identification of additional implementation options for reducing fish methylmercury in impaired reservoirs.

Second, the amount of water and sediment data available for each reservoir varied greatly. Staff assumed that the data used for the linkage analyses provide the best estimate of typical reservoir conditions. It is understood that additional data may alter the estimates for individual reservoirs used in the linkage analyses. Even so, the important factors identified by the linkage analyses are known from other studies to influence methylmercury accumulation in fish (see Appendix A and Chapter 4). Consequently, additional data are not expected to change the overall conclusions of the linkage analyses. However, the collection of additional data may better enable the selection of particular control measures for individual reservoirs and refinement of the aqueous methylmercury goal.

Third, data were not available for all factors identified in the conceptual model, particularly dissolved organic carbon, pH, degree of anoxia, and food chain length. The linkage analyses determined that three factors—the amount of inorganic mercury in the system, methylmercury production, and food web transfer—explain greater than 85% of the variability in reservoir fish methylmercury concentrations. This indicates that overall the most important factors have been identified. However, the collection of data for additional factors (e.g., food chain length and temporal and spatial extent of anoxia) may better enable the selection of particular control measures for individual reservoirs and may lead to the identification of additional implementation options.

Based on these considerations, the proposed implementation plan allows an improved and expanded data set to be collected and evaluated during Phase 1 of the implementation program. Further, the implementation plan should incorporate an adaptive management approach that allows the aqueous methylmercury goal to be re-evaluated after more information is collected.

6 SOURCE ASSESSMENT

Overview

Chapter Objectives

This chapter presents an assessment of mercury sources that contribute to impaired reservoirs across the state. The objectives of this source assessment chapter are the following:

- Provide an inventory and description of inorganic mercury sources; and
- Quantify current mercury concentrations of sources, with a focus on sources that have particularly elevated mercury concentrations and are substantial contributors of mercury to reservoirs.

The first section of this chapter describes the general approach to assessing mercury sources in California. Later sections provide detailed descriptions of each source type.

Foundation from Previous Chapters

The source assessment incorporates a concentration-based approach supported by the conceptual model and linkage analysis in Chapters 4 and 5. A concentration-based approach is taken when key factors (e.g. flow, season, source behavior) are variable. Coincidently, as discussed in Chapter 7, a concentration-based approach also better enables us to evaluate the feasibility of reductions for many mercury sources. Such an evaluation is needed because the linkage analysis determined that many reservoirs would require decreasing inorganic sediment mercury concentrations to lower than modern and natural background levels to achieve the proposed sport fish target based on source control alone.

This source assessment focuses on inorganic mercury sources for several reasons:

- The linkage analysis determined that reservoir sediment mercury concentrations have the strongest correlation with reservoir fish methylmercury concentrations of any single factor evaluated for California reservoirs. Sediment mercury concentrations are associated with multiple inorganic mercury sources such atmospheric deposition, upstream mine sites, and watershed soils.
- The conceptual model literature review indicated that reservoir water methylmercury concentrations are often dominated by within reservoir processes rather than watershed methylmercury sources.
- The conceptual model (Chapter 4) noted that mercury deposited from the atmosphere directly onto a water surface is likely the most bioavailable mercury source, mercury mining waste is likely one of the least bioavailable, and mercury from other sources falls

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Overview, continued

somewhere in between. However, mercury sources are not evenly distributed across the state. This source assessment indicates that many watersheds are dominated by a particular source. Some watersheds are dominated by mercury mining sources, while others are dominated by gold mining sources or watershed soils. Consequently, relative differences in bioavailability are not relevant to the amount of methylmercury in reservoir fish.

For these reasons, this source assessment does not incorporate the relative bioavailability of inorganic mercury sources or include methylmercury sources.

Key Points from Source Assessment

- Modern background soil mercury levels are elevated above natural background because mercury emissions and associated atmospheric deposition have increased greatly since the dawn of the industrial era. Modern background mercury levels vary greatly and are often much higher than natural background levels—as much as two to ten times higher. It could take decades to centuries for industrial-era mercury in watershed soils to be depleted.
- Historic gold and mercury mining activities were widespread in many of California's watersheds and most mining activities occurred upstream of reservoirs. However, 26 of the 74 mercury-impaired reservoirs on the 2010 303(d) List have no record of any historic gold or mercury mining in their watersheds.
- National and global emission inventories indicate that California anthropogenic emissions have decreased substantially in recent years while emissions in Asia have increased.
    - USEPA's Regional Modeling System for Aerosols and Deposition (REMSAD model) and the published literature indicate that anthropogenic emissions in California may account for only about 10% of atmospheric deposition in the state; anthropogenic emissions from elsewhere in the world account for about 60%; and natural (geologic) sources account for the rest.
    - About half of all modeled deposition in California attributed to California anthropogenic emissions occurs in just 10% of the state. At the five 303(d)-listed reservoirs with the highest direct modeled deposition rates, California anthropogenic emissions may contribute about 50 – 80% of all atmospheric deposition.
    - Air emissions may be the only substantial anthropogenic source to 29 of the 74 reservoirs on the 2010 303(d) List, and air emissions from outside of California may be the only substantial anthropogenic source to 17 of these 29 reservoirs.

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Overview, continued

- The majority of California's urban areas are downstream of reservoirs. Atmospheric deposition is the primary source of mercury in urban runoff. NPDES-permitted urban runoff and facility discharges may be substantial sources to only a couple of the 303(d)-listed reservoirs.
- Many 303(d)-listed reservoirs do not have elevated sediment mercury concentrations compared to modern and natural background levels. This indicates that many reservoirs are not substantially impacted by anthropogenic mercury sources within their watershed. That is, their sediment mercury concentrations instead are dominated by watershed soils and atmospheric deposition, even though some of these reservoirs are downstream of historic mines.

Implications

Regulating point sources, such as industrial facility and municipal wastewater discharges, is the conventional method to improve water quality. However, this source assessment indicates that the most important mercury sources to impaired reservoirs are nonpoint sources such as watershed soils, mine sites, and atmospheric deposition. Further, many 2010 303(d)-listed reservoirs do not have elevated sediment mercury concentrations. Thus, reducing watershed mercury sources may not result in substantial reductions in sediment and fish methylmercury concentrations in many reservoirs.

Consequently, it is necessary to consider whether source control actions can achieve the fish methylmercury targets in all reservoirs, especially given the importance of sources that cannot be regulated by California agencies, such as naturally-occurring mercury in watershed soils, and natural and global anthropogenic mercury emissions. Chapter 7 identifies which of the sources are potentially controllable and how much each source can be reduced. Chapter 7 also identifies other potentially controllable processes that may help reduce reservoir fish methylmercury concentrations. Consequently, the Implementation Plan (Chapter 9) includes actions to reduce inorganic mercury sources, in-reservoir mercury methylation, and methylmercury bioaccumulation in reservoir fish. Furthermore, if information generated during Phase 1 of implementation indicates that these actions are not adequate to achieve the fish methylmercury targets, an assessment of watershed methylmercury sources and potential allocations for those sources may need to be conducted at the end of Phase 1.

In addition, the elevated modern background soil mercury levels need to be considered when developing allocations for particle-bound mercury sources such as watershed soils and mine sites. The Chapter 7 assessment and the baseline information within this source assessment chapter provide the foundation for the allocations and implementation plan detailed in Chapters 8 and 9.

6.1 Approach to Assessing Mercury Sources

This assessment evaluates mercury sources throughout California, with a focus on the 74 mercury-impaired reservoirs on the 2010 303(d) List for which mercury control programs have not yet been adopted. This section describes the general approach to assessing mercury sources. The first two subsections describe the separation of point from nonpoint sources, and particle-bound from low-turbidity sources. The last subsection describes the geographic scope of the assessment.

6.1.1 Point and Nonpoint Sources

Mercury sources are characterized as either point sources or nonpoint sources. Point sources discharge mercury to water at a discrete location from human-engineered outfalls, pipes, and conveyance channels. Point sources include all sources subject to regulation under the National Pollutant Discharge Elimination System (NPDES) program. Point sources include wastewater treatment facilities, Municipal Separate Storm Sewer Systems (MS4s), and some discharges from mine sites.

Nonpoint sources include all remaining anthropogenic and natural mercury sources. Nonpoint sources include natural and anthropogenic mercury in atmospheric deposition; runoff from urban areas not encompassed by NPDES-permitted MS4s; erosion from diffuse mine waste material at mine sites, floodplains, and channels; and runoff from forested, agricultural, and other upland areas.

6.1.2 Particle-Bound and Low-Turbidity Sources

Mercury can be discharged by point and nonpoint sources directly to reservoirs or to streams and rivers in their upstream watersheds and ultimately transported to reservoirs. Mercury transport is closely tied to erosion and transport of soils and sediments (especially fine-grained particles and organic matter) because mercury is strongly associated with solids.[1] Soils and sediments are typically transported by precipitation and irrigation runoff, and associated natural and anthropogenic erosion. For this reason, the source assessment evaluates the following sources in terms of the mercury concentrations of their soils or sediments, or the mercury concentrations of suspended sediments (i.e., particulate mercury) in their runoff:

- Native geologic and soil formations in forested and other upland areas;
- Mine sites and associated downhill/downstream mine waste; and
- Urban areas.

In contrast, discharges from most types of NPDES-permitted facilities tend to be very low in suspended solids. As a result, this source assessment evaluates NPDES-permitted facility discharges in terms of total recoverable mercury in facility effluent. Finally, mercury in the atmosphere can be deposited in wet form (associated with precipitation such as rain, sleet,

[1] For examples, see: Domagalski 2001; Domagalski et al. 2004; Driscoll et al. 2007; Grigal 2002 and 2003; Kirchner et al. 2011; Louie et al. 2008; Mason and Sullivan 1998; Ruby 2005; and Whyte and Kirchner 2000.

snow, fog, and dew) or dry form (associated with particulate or gaseous settling). For this reason, this source assessment evaluates atmospheric deposition in terms of annual mercury load deposited per unit area (e.g., grams per square kilometer per year, g/km^2/yr).

6.1.3 Geographic Scope of Assessment

The statewide assessments of nonpoint mercury sources included atmospheric mercury deposition and background mercury levels in soils and sediments and point sources such as NPDES-permitted facility and MS4 discharges. In addition, it includes detailed inventories of point and nonpoint sources that contribute mercury to each of the 74 mercury-impaired reservoirs on the 2010 303(d) List for which mercury control programs have not yet been adopted. The watersheds of 303(d)-listed reservoirs comprise about a fifth the area of California; much of southern California not in 303(d)-listed reservoir watersheds is arid with few reservoirs. The literature review of common and not-so-common mercury sources indicates that the source inventories for the 74 303(d)-listed reservoirs are representative of mercury sources common elsewhere in the state. Consequently, the source assessment for 303(d)-listed reservoirs is expected to be representative of source conditions for mercury-impaired reservoirs that may be identified in the future.

6.2 Natural and Modern Background Conditions

This section describes natural and modern background mercury concentrations in soils and sediments. Natural background (pre-industrial) conditions reflect naturally-occurring mercury from native geologic formations. In contrast, modern background conditions include not only natural background but also contributions from atmospheric deposition resulting from industrial-era emissions. Further, this section describes where naturally mercury-enriched geologic formations and associated soils might occur in California. These evaluations address the following key questions:

- Which mercury-impaired reservoirs have naturally enriched geologic formations in their watersheds that could contribute to elevated reservoir sediment and fish mercury concentrations?"
- What are natural and modern background mercury concentrations for reservoir sediments and are reservoir sediments substantially affected by modern industrial-era emissions and anthropogenic sources in reservoir watersheds?
- What is the best way to characterize mercury concentration in sources that contribute particle-bound mercury, such as mine sites, given the influence of modern industrial-era emissions? This characterization will be used to develop allocations in Chapters 7 and 8.

The following sections provide an evaluation of the above questions based on a literature review as well as an analysis of soil and sediment mercury concentration data. In summary:

- Native soils have a dramatic range of mercury concentrations, especially in mercury mineralized zones and surrounding naturally mercury-enriched areas within the Coast Ranges. Naturally mercury-enriched soils contribute to elevated reservoir sediment and fish mercury concentrations in almost half of 303(d)-listed reservoirs.

- Modern background mercury levels in soils and sediments vary greatly and are typically much higher than natural background levels—as much as two to ten times higher. It could take decades to centuries for industrial-era mercury in watershed soils to be depleted.
- Modern background levels typically range from 0.05 to 0.1 milligrams per kilogram (mg/kg) in trace mercury areas, and 0.1 to 0.3 mg/kg in the mercury-enriched region. Reservoirs with average sediment mercury concentrations that exceed these ranges are likely significantly affected by discharges from local (watershed) anthropogenic mercury sources (e.g., mine sites) in addition to industrial-era mercury in atmospheric deposition from California and global sources.
- Reducing watershed mercury sources may not result in substantial reductions in reservoir sediment and fish mercury concentrations in many 303(d)-listed reservoirs. Sediment total mercury concentration data are available for 40 of the 303(d)-listed reservoirs. About half of these 40 reservoirs are substantially impacted by anthropogenic mercury sources within their watershed, based on sediment mercury concentrations. Conversely, the other half of these reservoirs reflect typical modern and natural background levels even though some are downstream from mines; thus, reducing industrial-era sources in these watersheds may not result in substantial reductions in reservoir sediment and fish mercury concentrations.

6.2.1 Three Mercury Regions in California

For source assessment purposes, the state can be divided into three regions: mercury mineralized zones, mercury-enriched region, and trace mercury areas. For the following description of the mineralized zones and mercury-enriched areas, Water Board staff relied on several papers and maps by the U.S. Geological Survey, California Geological Survey, and others (Churchill and Clinkenbeard 2003; Jenkins 1939; Pearcy and Petersen 1990; Rytuba 2000, 2002, and 2005; Rytuba et al. 2001; and USBM 1965).

Mercury-Enriched Region

The principal mercury (quicksilver) ore deposits of California are found in a large mineral belt that extends for about 400 miles along the Coast Ranges. This large mineral belt is referred to as the “Coast Ranges mercury-enriched region” or simply “mercury-enriched region” in this report. This mercury-enriched region contains 51 mercury deposits that have each produced over 1,000 flasks of mercury (a flask equals 76 pounds of mercury). Numerous smaller deposits, occurrences, and tracts of country (native) rock with elevated concentrations of mercury also are present in the mercury-enriched region. The primary ore mineral in all deposits is cinnabar but significant amounts of metacinnabar and native (elemental) mercury also may be present in some deposits. The majority of mercury deposits are associated with the Franciscan and Stony Creek geologic formations.

Mercury Mineralized Zones

Individual mercury ore deposits are generally small in area, rarely exceeding more than 1 km^2. The natural hydrothermal processes that form mercury deposits typically enrich surrounding host rocks in mercury for some distance outward from the ore deposits, from less than a meter to hundreds of meters. The degree of enrichment may be 10 to 100 times the natural background in the region. These mineralized zones may have mercury content above regional background because of effects of natural ore forming processes but contain lower mercury content than ore, typically in the range of a few tens to a few hundreds of parts per million of mercury. Due to native geology, the mercury-enriched region surrounding mercury mineralized zones often has elevated soil mercury concentrations compared to other areas of California, though not nearly as elevated as mineralized zones.

Maps of Mercury-Enriched Region and Mercury Mineralized Zones

Figure 6.1 illustrates the general location of geologic formations that may be associated with enriched mercury concentrations. Figure 6.1 also shows locations of major and minor mercury mining districts and historic mine sites, which are a strong indicator of mineralized and mercury-enriched geologic formations that could be at or near the ground surface. Figure 6.2 illustrates "districts known to be mineralized with quicksilver" in California identified in the "Economic Mineral Map of California No. 1—Quicksilver" (Jenkins 1939), which accordingly align well with historic mining districts and mine sites. All major mercury mining districts and the majority of known mineralized areas occur in the Coast Ranges. As noted earlier, mineralized zones have an aerial extent of a meter to hundreds of meters outward from ore deposits—too small to illustrate on a statewide map. Nevertheless, locations of key geologic formations, mercury mining districts, historic mercury mine sites, and soil mercury data can be used to delineate where naturally mercury-enriched soils are most likely to occur (Figure 6.2).

As shown in Figure 6.3, 28 of the 74 reservoirs on the 2010 303(d) List (about 40%) have watersheds within the Coast Ranges mercury-enriched region. As a result, native watershed soils may contribute to elevated sediment and fish mercury concentrations in these reservoirs.

Trace Mercury Areas

All areas outside of the mercury-enriched region are referred to as "trace mercury areas"—that is, areas with very low levels of mercury in their native geologic formations and soils. Such areas include geologic formations comprised of alluvium and lake deposits as well as metamorphic, plutonic (e.g., granitic), and volcanic rock formations.

Some of these formations may occasionally have relatively higher mercury concentrations, but typically are very low compared to mercury mineralized zones and mercury-enriched areas. For example, volcanic activity has the potential to release inorganic mercury into the air, so geologic formations in California with substantial ash deposits may contain higher concentrations of inorganic mercury. However, volcanic formations may or may not be enriched relative to crustal averages, perhaps because exceedingly high temperatures during some volcanic eruptions may preclude or limit mercury deposition by vaporizing the mercury (Hobara et al. 2009; Tomiyasu et al. 2003; Engle and Gustin 2002; Nacht and Gustin 2004).

6.2.2 Natural Background Mercury Levels

Understanding natural background (pre-industrial) conditions is critical for determining which reservoirs are substantially affected by modern, industrial-era sources. To determine natural background levels of mercury, staff reviewed mercury concentration data for (1) dated deep-core sediment samples collected in reservoirs and estuaries, and (2) soil core samples. Tables 6.1 through 6.3 summarize this sediment and soil data for mercury mineralized zones, mercury-enriched areas, and trace mercury areas.

Key findings for natural background soil and sediment mercury concentrations include:

- Mercury mineralized zones have a dramatic range, from an average mercury concentration of 15 mg/kg in the Oaks Arm of Clear Lake, to an average of 321 mg/kg at the Gambonini Mine Site, with a maximum of 990 mg/kg near a Cache Creek Watershed mine site, based on mineralized soils and dated (pre-industrial) sediment cores.
- Mercury-enriched areas have average mercury concentrations between 0.05 and 0.1 mg/kg, based on dated (pre-industrial) sediment cores in lakes, reservoirs, and estuaries.
- Trace mercury areas have average mercury concentrations about equal to or less than 0.03 mg/kg, based on dated (pre-industrial) sediment cores.

Consequently, reservoirs with average sediment mercury concentrations that exceed the mercury-enriched or trace levels indicate inputs from a pollution source. In general, reservoirs with average sediment mercury concentrations that exceed 0.1 mg/kg in the Coast Ranges mercury-enriched region or 0.03 mg/kg in trace mercury areas are likely affected by some type of industrial-era contamination from watershed or global anthropogenic mercury sources.

6.2.3 Modern Background Mercury Levels

This section focuses on modern background mercury levels in soils and sediments. Modern background levels reflect the combination of naturally-occurring mercury and contributions from atmospheric deposition resulting from industrial-era emissions. Understanding modern background conditions is critical for:

- Determining which reservoirs are substantially affected by industrial-era sources in their watersheds in addition to atmospheric deposition from regional and global industrial-era emissions; and
- Characterizing sources that contribute particle-bound mercury.

Soils naturally accumulate mercury deposited from the regional and global atmospheric pool of mercury. Most mercury in atmospheric deposition deposited to watersheds—70 to 99%—is stored in soils and vegetation long-term and released gradually over time.[2] As a result, soils have mercury concentrations that reflect increased mercury deposition since inception of the industrial period. This is considered the modern background condition (compared to natural background) because it will take decades to centuries for industrial-era mercury deposition stored in soils to be depleted.[3]

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[2] For examples, see: Tate et al. 2011; Harris et al. 2007; Grigal 2002; Swain et al. 1992; Lorey and Driscoll 1999; Mason et al. 1994; Dolan et al. 1993; Quemerais et al. 1999; and Johansson 2001.

[3] For examples, see: Golden and Knightes 2008; Harris et al. 2007; Perry et al. 2005; Lorey and Driscoll 1999; and Mason et al. 1994.

Modern background levels in some areas of California are affected by atmospheric deposition from regional industrial emissions in addition to global industrial emissions. For example, Rytuba (2002) found elevated background soil mercury concentrations to a depth of 33 centimeters (about 13 inches) in the New Idria Mercury District. Rytuba attributed the elevated mercury concentrations to long-term historic deposition from local ore roasting. Plouffe and others (2004) found elevated mercury concentrations in soils surrounding mercury mines at distances of up to 10 km. Emissions from historic mercury use at gold mine sites and modern industrial and urban sources also can contribute to atmospheric deposition that can accumulate in watershed soils. Although mining, industrial, and urban mercury sources may not be present in a given reservoir's watershed, the reservoir can still receive atmospheric deposition from those sources if the reservoir or parts of its watershed are downwind.

To determine modern background levels of mercury, staff reviewed mercury concentration data for:

- Soil samples collected throughout the state, excluding samples collected at mine sites and within urbanized areas; and
- Surface sediment samples (compared to deeper core samples) collected in lakes and reservoirs that have few or no mine sites, urban areas or other known anthropogenic sources in their watersheds.

Table 6.3 summarizes modern background soil mercury data for the mercury-enriched region and trace mercury areas. Because of the dramatic range of mercury concentrations observed in native material at mercury mineralized zones—1 to 1,000 mg/kg—contributions from atmospheric deposition are expected to be undistinguishable from the mercury already present in native material. Soil data for mercury-mineralized zones are reviewed in the previous section.

Modern background levels in California are often much higher than natural background levels. This is illustrated by the average mercury concentrations in dated sediment cores collected in six different lake and estuary locations across California (Table 6.2). Sediment mercury concentrations have increased by a factor of 2 to 14 times more than pre-industrial mercury concentrations, as shown by the comparison of average surface (modern) sediment results to deeper core sediment results. This indicates the importance of regional and global industrial-era mercury emissions and associated atmospheric deposition on background conditions.

The range of mercury concentrations in soils and sediments throughout the state also affects our understanding of modern background conditions (Tables 6.2 and 6.3, Figure 6.4). Key findings regarding modern soil and sediment mercury concentrations include:

- The Coast Ranges mercury-enriched region has significantly higher modern background concentrations than elsewhere in California (Table 6.3, Mann-Whitney, $p < 0.0001$), but they are not uniformly enriched throughout the region. Many locations in the mercury-enriched region have concentrations low enough to be comparable to areas outside the Coast Ranges (i.e., trace mercury areas).
- The Coast Ranges mercury-enriched region typically has mercury concentrations less than 0.3 mg/kg.

- Trace mercury areas typically have mercury concentrations less than 0.1 mg/kg.

Consequently, reservoirs with average sediment mercury concentrations that exceed these modern background levels for mercury-enriched or trace regions indicate a local (watershed) pollution source in addition to atmospheric deposition.

Recommendations

Staff recommends the following values be used to characterize region-specific, particle-bound mercury sources to reservoirs, which are based on the evaluations of background conditions:

- Trace mercury areas: 0.1 mg/kg
- Mercury-enriched region: 0.3 mg/kg
- Mineralized zones: 400 mg/kg

This characterization will be used to develop allocations in Chapters 7 and 8. These values take into account the variability observed in modern background levels. Because of that variability, especially in or near mercury mineralized zones and historic ore processing sites, local background soil data should be used to define site-specific cleanup goals.

Staff recommends that these values—0.3 mg/kg in the Coast Ranges mercury-enriched region and 0.1 mg/kg in trace mercury areas—be used to characterize region-specific, particle-bound mercury sources to reservoirs. These values take into account the variability observed in modern background levels observed in soil and sediment samples. Because of the great variability observed in soils and sediments throughout trace mercury and mercury-enriched areas, site-specific data should be used when available to define clean-up goals.

Staff recommends that 400 mg/kg be used to characterize particle-bound mercury sources to reservoirs in mineralized zones. Mercury concentrations of 400 mg/kg is comparable to the average concentration observed at the Gambonini Mine Site and to the 95th percentile concentration observed in background samples collected at mine sites in the Cache Creek watershed (see Table 6.1). Because of the great variability observed in mineralized zones, site-specific data should be used when available to define clean-up goals for sites within mineralized zones.

6.2.4 Reservoir Sediment Mercury Levels Compared to Background Levels

The evaluations of natural (pre-industrial) and modern background levels in California soils and sediments enable us to identify reservoirs with sediment mercury concentrations that may be significantly affected by global and local (watershed) anthropogenic sources.

For reservoirs in the Coast Ranges mercury-enriched region with average sediment mercury concentrations that are:

- Less than 0.1 mg/kg, natural background is likely the dominant mercury source;
- Between 0.1 and 0.3 mg/kg, natural background and industrial-era atmospheric deposition are the likely dominant mercury sources; and

- Greater than 0.3 mg/kg, there are likely substantial watershed anthropogenic sources in addition to natural background and industrial-era modern atmospheric deposition.

For reservoirs in trace mercury areas of California with average sediment mercury concentrations that are:

- Less than 0.04 mg/kg, natural background is likely the dominant source;
- Between 0.05 and 0.1 mg/kg, natural background and industrial-era atmospheric deposition are the likely dominant sources; and
- Greater than 0.1 mg/kg, there are likely substantial watershed anthropogenic sources in addition to natural background and industrial-era modern atmospheric deposition.

Reservoir sediment mercury concentration data are available for 44 reservoirs on the 2010 303(d) List (Table 6.4 and Figure 6.5). The comparison of reservoir sediment mercury concentrations to natural and modern background levels indicates that:

- 15 of 44 reservoirs have sediment mercury concentrations within the range of natural background levels. Thus, these reservoir sediments may not be substantially affected by industrial-era sources. Consequently, reducing industrial-era sources to these watersheds may not result in a substantial reduction in reservoir sediment and fish mercury concentrations.
- 13 of 44 reservoirs have sediment mercury concentrations within the range of modern background levels. Thus, although the reservoirs may have historic mine sites or other anthropogenic sources within their watersheds, the reservoir sediment mercury concentrations are likely most affected by mercury in atmospheric deposition from California and global industrial-era sources.
- 16 of 44 reservoirs have sediment mercury concentrations greater than modern background levels, 13 of which are downstream of historic mine sites and 3 of which are in heavily urbanized areas (see sections 6.3, 6.4, and 6.5 for more information about mining and urban sources).
- Of the 13 reservoirs downstream of historic mine sites, 7 have average sediment mercury concentrations that are more than two to ten times greater than the modern background level for their region.
- Of the 3 reservoirs in heavily urbanized areas, 1 has an average sediment mercury concentration that is four times higher than the modern background level for its region.

Thus, about half of the 303(d)-listed reservoirs have sediment mercury concentrations typical of natural and modern background levels. These background levels indicate that dominant sources of mercury to these reservoirs could be natural background alone, or the combination of natural background plus industrial-era mercury in atmospheric deposition.

In contrast, about half of the 303(d)-listed reservoirs have sediment mercury concentrations that exceed modern background levels. Several exceed by more than twofold, which indicates they receive substantial inputs from watershed anthropogenic mercury sources in addition to naturally occurring mercury and industrial-era mercury in atmospheric deposition. The following sections provide information about possible inputs from other local and global anthropogenic sources.

6.3 Historic Mines

This section identifies where historic mine-related pollution may contribute mercury to reservoirs, particularly those identified as mercury-impaired on the 2010 303(d) List. Specifically, this section briefly reviews historic mining practices in California, summarizes mercury concentrations in mining waste, and assesses historic mine sites based on geographical information system (GIS) databases. These evaluations address the key question: In what watersheds could mines contribute mercury to reservoirs that have elevated fish methylmercury concentrations?

Based on a literature review, soil mercury concentration data, and historic mine site GIS databases, staff concluded the following:

- Elevated food web mercury bioaccumulation in California is associated with both mercury mining and gold mining.
- 48 of the 74 reservoirs on the 2010 303(d) List have at least one historic prospect or productive mercury, gold, or silver mine site in their watersheds, and 9 of the 48 reservoirs have sediment mercury concentrations heavily impacted by historic mining waste.
- 26 of the 74 reservoirs on the 2010 303(d) List have no record of mining activities in their watersheds.
- Active erosion and discharges of mining waste pollute several 303(d)-listed reservoirs. Therefore, the implementation plan should assess and prioritize mine sites and their downstream areas.

6.3.1 Mercury Released to the Environment from Historic Mining in California

Millions of kilograms of mercury entered California's waterways from historic mercury, gold, and silver mining in the 1800's and early 1900's, and much of this occurred in watersheds upstream of modern-day reservoirs. Figure 6.1 shows major and minor historic mercury mining districts throughout California, and Figure 6.6 shows individual historic mercury, gold, and silver mine sites based on historic records. The USGS's Mineral Resources Data System (MRDS, USGS 2005) identifies more than 10,000 locations throughout California where productive mercury, gold, and silver mining may have taken place. Most historic mercury mines are in the Coast Ranges, while most historic gold mines are in the Sierra Nevada with additional clusters in northwestern and southeastern California, and most historic silver mines are in eastern and southern California.

The following sections provide brief histories of mercury, gold, and silver mining in California, summaries of historic mining processes, and available estimates of mercury lost to the environment from historic mining operations. Staff relied on mercury loss estimates calculated by staff of the California Department of Conservation (CDOC) (Churchill 2000) as well as historical information provided by several papers, databases, and maps by the U.S. Geological Survey (USGS), CDOC, The Sierra Fund, and others.[4]

Mercury Mining

About 90% of mercury mined in the United States was mined in California. Total mercury production in California between 1846 and 1981 was about 104 million kilograms (M-kg). Mercury mining in the Coast Ranges reached a peak annual production of about 3 M-kg in 1877, and about 74 M-kg of mercury valued at about $102 million was produced by 1917.

The MRDS indicates there were over 300 historic mining sites where mercury was the primary commodity, with the greatest concentration of mercury mines in Lake County. Based on historic records, the CDOC Division of Mines and Geology identified 239 mines with production of at least one flask (~34 kg) of mercury. The 25 largest mines accounted for nearly all—about 100 M-kg—of the total mercury production. The two largest mines, New Almaden Mine in Santa Clara County and New Idria Mercury Mine in San Benito County, produced about 37 M-kg and 17 M-kg of mercury, respectively, and accounted for more than half of all mercury mined in California. Most mercury was exported to the Pacific Rim, shipped to Nevada for use in processing the Comstock Lode silver ores, or transported to other western states. About 10 − 12 M-kg remained in California for use in gold recovery.

Mercury ore deposits in California were mined by both underground and open pit methods. Mercury ore was typically mined at relatively shallow depths of 500 feet or less. The two notable exceptions were the New Almaden Mine and New Idria Mine, which at their lowest levels were mined at 2,450 feet and 1,060 feet, respectively. The only major deposit mined by open pit methods in California was the Sulphur Bank Mine in Lake County. Mercury ore was crushed and roasted in large furnaces or retorts[5], a process known as calcination. Heating the ore broke down the mercury sulfide ore minerals and produced sulfur dioxide and mercury vapor. The mercury vapor was distilled, condensed, and collected as liquid mercury in flasks. Mercury was released to the environment in various forms, including vaporized elemental mercury from the roasting process, mercury still entrained within the crushed sulfide ore (calcine), fine particles from the roasting ovens, and spillage of liquid mercury during handling.

Churchill (2000) estimated 34 M-kg of mercury may have been lost to the California environment from historic mercury mining activity, assuming an average loss rate of 25%. Much of the mercury mining and extraction occurred prior to 1890 when mercury processing was crude and inefficient. Over time, mercury recovery methods improved and losses to the environment were reduced. By 1890, 15 – 20% losses could be achieved at well-run plants, but

[4] Citations for historic mining operations and mercury loss estimates: Alpers et al. 2005; Beard 1987; Bowie 1905; Bradley 1918; CDOC 2000; Churchill 2000; Clark 1998; Hausel 2010; Hanks 1882; Hayes 2014; Hill et al. 2001; Hunerlach et al. 1999; Kim et al. 2000; Kirkemo et al. 1997; Rawls and Orsi 1999; Roush 1952; SFBRWQCB 2008b; The Sierra Fund 2008; UNEP 2010; USFS 1995; USEPA 2000a, 2011, and 2013; USGS 2005; Wells et al. 1958.

[5] A retort is a small-sized mercury ore processing device where ore was processed in batches by loading it into metal tubes in a small brick structure that was typically heated by burning wood; the mercury vapor produced within the retort tubes was cooled and condensed in small metal condensing tubes (Clinkenbeard and Churchill 2003). Retorts generated relatively small amounts of mining wastes (Churchill and Clinkenbeard 2003),

losses could be as much as 40% at poorly run plants. By 1917, overall losses were believed to be about 25%, and by 1950 losses of 5 – 10% were achieved at the best plants.

Gold Mining

The "Gold Rush" era began in January 1848 when gold was discovered at Sutter's Mill in Coloma in the Sierra Nevada foothills, although gold was first mined in the late 18^{th} and early 19^{th} century in southern California. Gold production varied considerably and reached its highest annual production in 1852 at nearly 4 million ounces (~0.1 M-kg). The total recovery of gold in California likely exceeded 100 million ounces (~3 M-kg).

There are more than 10,000 historic gold mining sites in California where gold was a major commodity, representing almost half of all commodity mining sites in the state. Although gold has been found in many areas of California, the most productive mining districts were in the northern and central Sierra Nevada, and the second most productive districts were in the Klamath-Trinity region. The basin ranges of eastern California and the Mojave Desert in the south also yielded substantial amounts of gold where it was found in volcanic, metamorphic, and plutonic (e.g. granitic) rocks. Moderate amounts of gold were recovered from the Transverse and Peninsular Ranges in southern California. Other areas where gold was recovered include the Modoc Plateau in northeastern California, and several locations in the Coastal Ranges.

<u>Gold mining methods</u>. The most prevalent gold mining methods were placer mining of upland alluvial deposits, hard rock mining of gold-quartz veins (also called "lode" mining), and dredging of alluvial deposits. At first, placer mining methods in streams and riverbeds used pans, cradles, rockers, sluices, long-toms (portable sluice boxes), and trommels (rotating screens) to recover gold from river gravels (placer deposits). Hydraulic mining of upland placer deposits made use of high pressure water streams, also referred to as water cannons, to break the ore-bearing rock into smaller pieces. The rocks would then be directed into sluices so the gold and rock could be more easily separated. Per The Sierra Fund (2008), "Hydraulic mining was very successful in the Sierra because abundant surface water was available. By 1865, miners had constructed an estimated 5,000 miles of flumes, ditches, and canals to convey water to mine sites across the western slope of the Sierra. Later these canals and associated reservoirs became the basis of the water rights and infrastructure for hydroelectric power generation and the state's water supply system."

From the 1850s to the 1880s, hydraulic mining processed more than 1.5 billion cubic yards of gold-bearing placer gravels in the northern Sierra Nevada region and recovered about 0.3 M-kg of gold. The resulting debris moved by hydraulic mining damaged downstream property and caused flooding. The 1884 Sawyer Decision made by the United States Ninth Circuit Court prohibited discharge of hydraulic mining debris to rivers and streams in the Sierra Nevada region. Congress passed the Caminetti Act of 1893, which allowed hydraulic mining to occur as long as downstream movement of sediment was controlled by debris dams such as Englebright Dam on the Yuba River. Hydraulic mining continued until 1950 in the Klamath-Trinity Mountains.

Underground mining of placer deposits (drift mining) and gold-quartz veins (lode mining) involved excavating shafts and tunnels or quarrying, and then blasting the exposed ore veins to remove gold-containing rock. The rocks were brought to the surface, crushed in stamp mills and ball mill facilities, and then separated from the gold by physical means such as sluicing. Hard rock mining produced most of California's gold from the mid-1880s to the 1930s, accounting for about 60% of the gold produced in the Sierra Nevada foothills. Hard rock mines in the Sierra Nevada foothills operated for almost 100 years, until 1942 when most were shut down by presidential order during World War II, though some continue to operate today.

Historical mining methods also included diverting streams (to prospect the exposed streambed) and dredging alluvial river bottoms and floodplains (to access gold-bearing sediment deposits). By the late 1890s, dredging techniques had become economical and from then through the 1960's dredging in the Sierra Nevada foothills recovered more than 0.5 M-kg of gold. From the mid-1880s to the early 1900s, dredging operations mined over 3.6 billion cubic yards of material and produced most of California's gold. Some dredging operations continued until 2003. Dredging operations used large machines to excavate alluvial sediment, rocks, and gravel with a continuous bucket line. The dredged material was then filtered through rotating steel cylindrical screens. The separated large cobbles were considered waste tailings (stacker tailings) and stacked behind the dredger while small (usually 0.75 inch and less gravel and sediment) material was directed to a sluice box.

<u>Mercury use and loss</u>. Gold was recovered by mechanical settling and density separation, as well as chemical reaction with liquid mercury to form gold-mercury amalgam. For example, mercury was added to sluice boxes used with placer and dredge mining to bind with the fine-grained gold, making it easier to separate the gold from the sediment. During hydraulic mining operations, several hundred pounds of liquid mercury would be added to the sluice boxes. In hard rock mining, mercury was added to crushed ore. The gold-mercury amalgam was collected and heated until the mercury vaporized and relatively pure gold remained.

Although many recovery operations distilled the mercury vapor for reuse, much of the vapor was lost to the environment where it would eventually be deposited back onto the land and waterways. Loss of mercury during gold processing was estimated to be 10 to 30% per season, resulting in highly contaminated sediments at mine sites, especially in sluices and drainage tunnels. Some mercury was lost from sluices, either by leaking into underlying soils and bedrock or being transported downstream with the placer tailings. The water flowing through the sluice caused many of the finer gold and mercury particles to wash through and out of the sluice before they could settle in the mercury-laden riffles.

Mercury also was lost to the environment in the form of "floured" mercury. The pounding of cobbles and gravels over liquid mercury in sluice boxes caused the mercury to break into extremely small globules, which gave it a white, flour-like appearance. Intense grinding in the hard rock milling systems also formed floured mercury. The formation of floured mercury was aggravated by agitation, exposure of mercury to air, and other chemical reactions. If the floured mercury had surface impurities such as oil, grease, clay or iron and base metal sulfides, it would not coalesce into larger drops or form an amalgam with gold. The floured mercury was transported downstream with tailings. Minute particles of mercury could be found floating on surface water as far as 20 miles downstream of mining operations.

In addition, mercury was lost to the environment by erosion and downstream transport of mine tailings, as well as by re-use of mine tailings. Hard rock mining left deposits of sand-sized sediment in mill tailings, and hydraulic mining left behind vast deposits of gravel-sized sediment in downstream streams and rivers, and flood deposits of sand and silt at lower elevations. Per The Sierra Fund (2008), “For more than 100 years it was common practice to use the tailings from former mine sites for construction of buildings, highways, and roads. Toxic materials such as mercury, arsenic, and asbestos contained in the tailings were thus distributed far and wide across California’s Gold Country.”

Historical records indicate more mercury was used and lost by hydraulic mining than by other types of mining. Per Churchill (2000), “... probably about one pound of mercury was lost for every three or four ounces of gold recovered... Other methods of processing placer deposits recovered 5 to 10 times this amount of gold per pound of mercury lost. Mercury loss at stamp mills gradually decreased over time from about 0.06 pounds of mercury per ton of ore processed in the 1850s to about 0.03 pounds per ton in the 1890s and finally to about 0.004 pounds per ton for the 1930s and later...” Mercury losses decreased because of improvements and changes in mining methods as well as a change in the character of gold ores as the lode mines deepened. In 1887, the gold mining industry began using cyanide leaching to separate gold from ore. Per Churchill (2000), the “cyanide process reduced or eliminated the need for gold recovery by mercury amalgamation at some mines. Traditional stamp mill methods did not work well on the deeper, unoxidized ores, and different ore processing methods were often utilized.” Mercury continued to be used in dredging operations until the early 1960s.

Churchill (2000) estimated that about 5.8 M-kg of mercury may have been lost to the California environment from historic gold mining activity, as follows. Churchill (2000) estimated that the amount of mercury lost from all placer mining operations in California was about 4.5 M-kg, based upon estimates of the amount of placer gold produced during different periods and published mercury loss rates per ounce of gold produced for different placer mining methods. About 70% of this loss occurred between 1859 and 1884, the principal period of hydraulic mining in California. About 80 to 90% of the loss from placer mining operations was in the Sierra Nevada geomorphic province. Based on the amount of lode gold ore processed during different periods and the approximate mercury loss rates for those time periods, Churchill (2000) estimated the amount of mercury loss in the milling of lode gold ore to be about 1.3 M-kg.

Silver Mining

In 1859, a body of high grade silver was found at Virginia City, Nevada and was named the Comstock Lode discovery. This discovery led California miners to explore farther and discover more silver and many new commodities in California’s eastern Sierra Nevada and Mojave Desert. Many productive silver lodes are in southern California, particularly in Inyo and San Bernardino Counties.

In 1878, new legislation requiring government silver purchases made silver paramount to gold, and often, the metal of choice by miners throughout the West. Although many of the larger operations closed after 1893 when silver prices collapsed, silver continued to be an important mineral mined in California until the 1950s. There were more than 600 historic silver mines in California. Silver is still recovered and processed as a byproduct of gold production in California.

Although silver can be mined in open pits, it was generally extracted by hard rock mining techniques. Mercury was used as an amalgam in the recovery of silver from ore. Mercury loss at the Comstock Lode has been estimated at about 6.8 M-kg, which exceeds the estimated loss in all of California from gold mining operations by almost 1 M-kg. However, estimates of mercury loss from silver mining operations within California are not available. Today, as with gold, cyanide leaching is widely used in the extraction of silver from ore.

6.3.2 Mining Waste Mercury Levels, Transport, and Bioavailability

Mining waste from historic mining is a continuing source of mercury to downstream reservoirs. The California Department of Conservation estimated there are almost 50,000 abandoned mines in California and more than 160,000 mining features throughout the state (CDOC 2000 and 2013). Of these, about 11% present environmental chemical hazards (versus physical safety hazards) including mining waste at historic mine sites (CDOC 2000). Given elevated mercury concentrations in present-day mining waste, hundreds to thousands of kilograms of mercury may remain at historic mine sites (Alpers et al. 2005; Churchill and Clinkenbeard 2003).

Mining waste and mercury-contaminated sediments have a dramatic range in mercury concentrations, that is, multiple orders of magnitude greater than background soil and sediment levels. For example:

- Mercury can occur in elemental (liquid) form in drainage tunnels and sluices, and in liquid and floured form in stream channels downstream of historic gold mining operations (CDM 2002; Hunerlach et al. 1999; USFS-TNF 2002).
- Elemental mercury also can be found in small quantities in mercury mining waste piles (SFBRWQCB 2008).
- Mercury concentrations typically range from about 10 mg/kg to 400 mg/kg in soils and sediments at and downstream from mercury mine box culverts and calcined tailings (mining wastes), and as high as 1,000 to 3,000 mg/kg in processing site soils and other waste materials in the immediate area of furnaces and retorts (Churchill and Clinkenbeard 2003; Montoya and Pan 1992; Rytuba et al. 2001; SFBRWQCB 2008; Weston Solutions, Inc. 2010).
- Mercury concentrations typically range from about 0.1 mg/kg to 100 mg/kg, and can be as high as 1,000 to 30,000 mg/kg, in soils and sediments at and downstream from hard rock and placer gold mine sluice boxes, tailings, and waste rock dumps (Alpers et al. 2006; CDOC 2003; Henson et al. 2008; Hunerlach et al. 1999; USEPA 2000a).
- Mercury concentrations range from about 0.01 mg/kg to 1 mg/kg in dredge tailing and pond sediments (Ashley and Rytuba 2008; Slowey et al. 2005; Stillwater Science 2004).

Exposed mining waste from historic mining operations continues to contribute mercury to downstream streams and reservoirs. Mercury in exposed mining waste is readily mobilized by seasonal precipitation runoff, mine drainage, and erosion processes.[6] Mercury transport is closely tied to water flows, and the most significant transport occurs in wet months. Mercury is transported predominantly in inorganic particulate form. In addition, mercury can be transported as dissolved mercury mobilized by small storms and mine drainage, and as methylmercury produced in impoundments and channels during the dry season.

Once in the aquatic environment, mercury from gold mining appears to be more biologically available than material from mercury mines (Bloom 2003; Heim et al. 2003). Even so, elevated food web mercury bioaccumulation is associated with both mercury mining and gold mining in California (Gehrke 2011; SFBRWQCB 2007b; CH2MHill 2008; Cooke and Morris 2002; Cooke et al. 2004; Hunerlach et al. 1999; SFRWQCB 2008; Slotton et al. 1997).

6.3.3 Reservoirs That May Be Affected by Mining Waste

Many reservoirs are directly affected by past and present discharges from historic mercury, gold, or silver mine sites, dredge tailings, and placer tailings in their watersheds. This section evaluates where sediment mercury levels in 2010 303(d)-listed reservoirs may be elevated due to the presence of upstream historic mines and mining wastes, based on the following databases:

- USGS's Mineral Resources Data System (MRDS, USGS 2005)
- CDOC's Principal Areas of Mine Pollution (PAMP) database (OMR 2000)
- CDOC's Topographically Occurring Mine Symbols (TOMS) database (OMR 2001)
- USGS's Database of Significant Deposits of Gold, Silver, Copper, Lead, and Zinc in the United States (Long et al. 1998)

The evaluation determined that 48 of the 74 303(d)-listed reservoirs have at least 1 historic prospect or productive mercury, gold, or silver mine site in their watersheds, with 9 of 48 reservoirs having sediment mercury concentrations heavily impacted by historic mining waste. In contrast, 26 of the 303(d)-listed reservoirs—about one third—have no record of mining activities in their watersheds.

Location of Historic Mining Activities

Past and present discharges from historic gold and mercury mines may be particularly important sources to reservoirs with a high number of mine sites, high watershed mine density, or high mine production (and associated mercury loss) amounts (Shilling et al. 2002; Scudder et al. 2009; Alpers, 2016). Figures 6.6 through 6.8 show locations of historic mercury, gold, and silver mines identified in the MRDS, PAMP, and TOMS databases. Figure 6.9 summarizes the number and density of historic mine sites in each 2010 303(d)-listed reservoir watershed as well as estimates of gold and silver production and associated mercury losses in each watershed. Tables C.1 through C.5 in Appendix C provide additional summaries of the number, type, and

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[6] For example: Churchill and Clinkenbeard 2003; Johnson et al. 2010; Hunerlach et al. 1999; Kirchner et al. 2011; Montoya and Pan 1992; Weston Solutions, Inc. 2007; Whyte and Kirchner 2000.

watershed density of mercury, gold, and silver mines within the 303(d)-listed reservoir watersheds.

The USGS's MRDS database and Database of Significant Deposits indicate:

- There are over 25,000 historical mercury, gold and silver mining features throughout California. These features include prospects, productive mines, mineral occurrences, and sites with unknown status. The MRDS identifies over 14,000 prospects and productive mine sites. About half of the historic mining features are upstream of 303(d)-listed reservoirs.
- Of the 74 303(d)-listed reservoirs, 48 have at least 1 historic prospect or productive mercury, gold, or silver mine site in their watersheds; 24 reservoirs have more than 50 productive mine sites; and 17 reservoirs have more than 100 productive mine sites.
- Gold and mercury—not silver—were most often the major commodities at the productive mine sites.
- The Berryessa and Nacimiento watersheds have the most productive historic mercury mining sites, while the Marsh Creek and Davis Creek watersheds have high mercury mine site densities because of their small area.
- The Camp Far West and Wildwood watersheds have high densities of historic gold mine sites, as well as high gold production and mercury loss estimates given their small areas. These watersheds have very high potential for reservoir sediment mercury contamination from historic mining waste.
- The Englebright, Natoma, Tulloch, and Don Pedro watersheds have elevated mercury loss estimates because of extensive historic placer mining. These watersheds also have high potential for reservoir sediment mercury contamination from historic mining waste. Erosion from the immense Natoma and Don Pedro watersheds may provide sediment with background mercury concentrations that likely mixes with and dilutes or buries mercury from historic mining operations.
- The remaining 26 reservoirs on the 2010 303(d) List have no record in the MRDS database of any mercury, gold or silver prospects or mine sites in their watersheds.

The California Department of Conservation's PAMP database indicates:

- There are at least 139 mercury mine sites and 6 gold mine sites throughout California with potential mercury pollution; 38 of these are upstream of 303(d)-listed reservoirs.
- Of the 74 303(d)-listed reservoirs, 9 have at least 1 mine site with potential mercury in their watersheds identified by California Department of Conservation.
- All of the 303(d)-listed reservoir watersheds that had no MRDS prospect or productive sites also had no PAMP sites.

The TOMS database indicates:

- The majority of dredge tailings in California are located downstream of reservoirs, while placer tailings and diggings are located upstream of reservoirs.

- Of the 74 303(d)-listed reservoirs, 18 have some combination of dredge tailings, placer tailings, and diggings in their watersheds.
- Only 2 303(d)-listed reservoirs have more than 1 km^2 of dredge tailings within their watersheds: Lake Natoma (12.3 km^2) and Beach Lake (8.3 km^2) (see Table C.6 in Appendix C).
- Five 303(d)-listed reservoirs have more than 1 km^2 of placer tailings and diggings within their watersheds: Lake Englebright (14.4 km^2), New Bullards Reservoir (5.5 km^2), and Rollins Reservoir (6.3 km^2). Camp Far West Reservoir and Lake Combie are downstream of Rollins Reservoir on the Bear River; the TOMS database does not include any placer tailings or diggings in the Bear River watershed downstream of Rollins Reservoir.
- All of the reservoirs with dredge tailings, placer tailings, and diggings in their watersheds except Beach Lake also have moderate to high watershed mine site densities and high mercury loss estimates associated with historic placer gold mining.

Five of the 2010 303(d)-listed reservoirs are likely affected predominately by mines located upstream of other reservoirs. Thermalito Afterbay and Lake Solano are immediately downstream of major reservoirs (Thermalito Forebay and Lake Berryessa, respectively). These major reservoirs have an abundance of historic mine sites in the *distant* portion of their watersheds upstream of other reservoirs. However, Thermalito Afterbay and Lake Solano appear to have no historic mine sites or dredge fields within their *immediate* watershed area downstream of major reservoirs. Similarly, Woodward, Modesto, and Turlock Reservoirs are off-stream reservoirs with no historic mine sites or dredge fields within their immediate watersheds; however, these reservoirs are supplied by water diversion dams on rivers immediately downstream of reservoirs (Tulloch and Don Pedro) in watersheds with high gold mine site densities. Consequently, these five reservoirs also may receive inputs from historic mining activities.

Reservoir Sediment Mercury Concentrations and Upstream Mining Activity

As discussed in section 6.2.4, reservoir surface sediment mercury data are available for 44 of the 74 reservoirs on the 2010 303(d) List. All 16 of the 303(d)-listed reservoirs with average sediment mercury concentrations elevated above modern background levels have watersheds with moderate to high mercury and gold mine site densities. The 9 reservoirs with high mine site densities and elevated sediment mercury concentrations include the following: Lake Berryessa, Marsh Creek Reservoir, and Lake Nacimiento (mercury mining); and Lake Wildwood, Camp Far West Reservoir, Lake Combie, Rollins Reservoir, Englebright Lake, and New Melones Reservoir (gold mining). Englebright, New Bullards Bar, Wildwood, Camp Far West, Combie, Rollins, Tulloch, and New Melones reservoirs had the highest watershed mining production-related mercury loss rates (loss per unit watershed area, see Figure 6.9). (Feasibility notwithstanding, remediation of mine sites and contaminated material in stream channels would be expected to be particularly effective at reducing fish methylmercury concentrations in these reservoirs. Feasibility of remediation considered in Chapter 7.)

However, reservoirs can have relatively low sediment mercury concentrations in spite of having numerous gold mine sites in their watersheds. For example, 26 of the 2010 303(d)-listed reservoirs with sediment mercury data have elevated watershed mine site densities (Tables 6.4 and C.5); of these, 13 have sediment mercury concentrations within modern background levels, and 7 of these 13 reservoirs have sediment mercury concentrations within natural background levels. Thus, mine remediation may not result in substantial fish methylmercury reductions in these reservoirs; more discussion is provided in Chapter 7.

Consequently, watershed mine site density may not be a reliable indicator of where elevated reservoir sediment mercury concentrations may occur, except perhaps where there are extremely high mine densities (e.g., Camp Far West, Combie, Rollins, and Wildwood Reservoirs). The inconsistent association between mine site density and reservoir sediment mercury concentrations could be the result of several possible factors, including but not limited to:

- Sediment mercury data may not have been collected in a manner that captured the full influence of upstream mine sites. For example, at many reservoirs, data are comprised of one to three grab samples at central well-mixed locations. However, contaminated sediment may be more localized to the tributary arms that drain the subwatersheds with substantial mine inputs, causing reservoir sediment mercury concentrations to be more elevated at tributary arms than at central locations. Such a spatial distribution of elevated and background sediment mercury concentrations has been observed at several reservoirs in the Coast Ranges (e.g., Clear Lake, Lake Berryessa, Lake Nacimiento) and elsewhere in California (e.g., Lake Oroville) (Cooke et al. 2002; CCRWQCB 2002; CVRWQCB 1987).
- Because these mines are legacies from long ago, there may not be on-going erosion of mine-contaminated material from many mine sites or their downstream creeks, and so contributions from these mines may no longer appreciably affect downstream reservoirs.
- Mine density may not be a consistent indicator of the magnitude of mercury contributions to reservoir sediment concentrations, but neither are estimates of gold and silver mines production and associated mercury loss. For example, several reservoirs with low sediment mercury concentrations likely had high mining-related mercury releases in their watersheds (e.g., New Bullards Bar) (Chart E in Figure 6.9). To determine a better indicator of mining contributions to watersheds, USGS staff is conducting more comprehensive evaluations of historic records, aerial imagery, and other potential indicators (Alpers, 2016). Their evaluations could enhance understanding of historic mercury releases and where mining-related contamination could occur in watersheds.
- Mercury in gold mining regions may be present more in its elemental form and not well captured by reservoir sediment sampling efforts.
- Many reservoirs are in watersheds with multiple upstream dams that trap mercury-contaminated material from upstream mine sites.
- Large watersheds may have enough sources of sediment not affected by mine waste to mix with and dilute or bury inputs from mine sites.

Nonetheless, active erosion and discharges of mining waste pollute downstream waters, including several 303(d)-listed reservoirs. Therefore, the implementation plan (Chapter 9) calls for an assessment and prioritization of mine sites and their downstream areas.

6.4 Atmospheric Deposition

This section describes the local (California) and global sources that emit mercury to the atmosphere, and provides an estimate of how much of the mercury emitted is deposited in California, in particular to 2010 303(d)-listed reservoirs and their watersheds. Evaluating emission sources and deposition addresses several key questions:

- How much atmospheric mercury is deposited in California and where does it come from?
- Where are there elevated rates of mercury deposition and are they caused by anthropogenic emissions in California or other sources?
- Where might anthropogenic emissions in California account for a substantial portion of atmospheric deposition?
- What are the emission sources that contribute most to deposition to mercury-impaired reservoirs?
- Are there any mercury-impaired reservoirs where atmospheric deposition is the primary anthropogenic mercury source?

This evaluation found:

- About 5,300 kg of atmospheric mercury were deposited in California in 2001 according to USEPA's Regional Modeling System for Aerosols and Deposition (REMSAD). The REMSAD model attributed only about 10% of the 2001 deposition to anthropogenic emissions from California facilities. The model attributed the majority (about 90%) of deposition to natural and global anthropogenic emissions.
- California's anthropogenic emissions come from a variety of sources, primarily Portland cement production, mobile sources (on-road diesel vehicles and non-road diesel equipment), municipal and hazardous waste incineration, geothermal power production, petroleum refineries, and oil and gas extraction. In contrast, almost half of global anthropogenic emissions come from fossil fuel combustion for power and heating (primarily coal combustion). Other large global sources include artisanal and small-scale gold production, metal production, and cement production.
- There were 18 hotspot areas in California in 2001 where California anthropogenic emissions may account for 20% or more of all deposition, with some areas as high as nearly 90%, according to the REMSAD model. However, emissions in 16 of the hotspot areas substantially decreased since 2001. Overall, California's anthropogenic emissions have decreased by more than 50% since 2001.
- Atmospheric deposition is the primary anthropogenic source to about 40% of the 303(d)-listed mercury-impaired reservoirs in California. REMSAD attributes more than 50% of atmospheric deposition to California anthropogenic emissions at three of these reservoirs: El Dorado Lakes, Indian Valley Reservoir, and Puddingstone Reservoir. Emissions from municipal waste incineration, geothermal power production, and cement plants are likely the most important anthropogenic contributors to these reservoirs. However, emissions from these sources have decreased by 60 – 70% since 2001.

The following sections provide our evaluation for the above questions and provide recommendations for baseline values. This evaluation will be used to develop allocations in Chapters 7 and 8.

6.4.1 Natural Emissions

Global mercury emissions from natural processes include contributions from (1) primary natural sources and (2) secondary re-emission of historically deposited mercury from natural and anthropogenic sources that settle on land, vegetation, and water surfaces (Figure 6.10). Primary natural sources include volcanoes, calderas, geothermal vents, geologic deposits, and volatilization from the ocean. Re-emission of historically deposited mercury is primarily related to land use changes, biomass burning (e.g., forest fires), meteorological conditions (e.g., wind-blown dust), microbial activity, and exchange mechanisms of gaseous mercury at air-water, top soil, snow, and ice pack interfaces (Pirrone et al. 2010; Mason 2009; USEPA 2008a; Cox et al. 2009).

Mercury emissions from natural processes account for about 60 – 70% of all global emissions (Pirrone et al. 2010; Selin et al. 2007; Seigneur et al. 2004; Mason and Sheu 2002; Shia et al. 1999; Bergan et al. 1999). However, mercury emissions from only natural sources (excluding re-emissions of historically deposited mercury from anthropogenic sources) account for only about 29 – 33% of global emissions (Selin et al. 2007; Seigneur et al. 2004; Mason and Sheu 2002; Shia et al. 1999; Bergan et al. 1999).

6.4.2 Historic Anthropogenic Mercury Emissions

Although mercury emissions from human activities began with domestication of fire, their influence on air quality on a global scale became pronounced during the Roman Empire from uncontrolled smelting of large quantities of ores in open fires, especially in Europe and China (Nriagu 1996). Between 1580 and 1820, mercury emissions from silver production in Central and South America ranged from about 292 to 1,085 metric tonnes per year (Nriagu 1993). Later, there was an exponential increase in metal emissions during the Industrial Revolution (about 1750-1850) (Nriagu 1996; Hong et al. 1996).

Mercury pollution in the Americas was dominated by mercury emissions from gold and silver production related to the mercury amalgamation process. Similar to Central and South America, between 1850 and 1920 in North America, mercury emissions from gold and silver production ranged from about 200 to 1,700 metric tonnes per year (Figure 6.11); losses increased between 1850 and 1880 and then steadily decreased as the cyanide concentration technique replaced mercury amalgamation (Pirrone et al. 1998). Estimates of historic mercury emissions from gold and silver production in the Americas greatly exceed estimates of current anthropogenic emissions.

As discussed earlier (sections 6.2 and 6.3), historic industrial (anthropogenic) emissions are reflected in elevated soil mercury levels at specific industrial (e.g., mining) sites and in regional background mercury levels in California's soils and sediments distant from mining sites. The following sections focus on recent local and global anthropogenic mercury emissions and associated deposition in California.

6.4.3 Recent Anthropogenic Mercury Emissions

As noted at the beginning of this chapter, atmospheric deposition is considered a nonpoint source discharge into water. Nonetheless, anthropogenic emissions that contribute to atmospheric deposition can be divided into point and nonpoint mercury emissions:

- Nonpoint emission sources include: on-road motor vehicles (e.g., light- and heavy-duty vehicles) and non-road equipment (e.g., generators).
- Point emission sources include:
  - Facility emissions, which are usually associated with emissions from a stack.
  - Area-wide emissions, which are typically diffuse, small, too numerous to assess individually, and not usually associated with emissions from a stack. Area-wide emissions include residential fuel combustion (e.g., fireplaces), motor vehicles, fires, emissions from laboratories, and some emissions from waste disposal activities and mobile sources such as commercial marine vessels and locomotives.

Nonpoint emissions and area-wide point-emissions data typically are reported in literature and databases as county totals. In contrast, facility emissions data are reported for facility-specific geographic locations, and often emission information is available for different processes at a given facility.

To characterize recent anthropogenic mercury emission sources and trends in California and elsewhere in the world, numerous detailed annual emission inventory databases and inventory summaries were relied upon:

- Global inventories and summaries for 1990, 1995, 2000, and 2005, which include point and nonpoint anthropogenic emission sources (Pacyna 1996; Pacyna et al. 2002, 2006, and 2010; Pirrone et al. 2010; AMAP/UNEP 2008).
- National Emissions Inventory (NEI) databases of emissions in the United States for 2002, 2005, and 2008, which include point and nonpoint emission sources, as well as NEI summaries for 1990, 2005, and 2008 prepared by the USEPA (USEPA 2012a; USEPA 2012b, Table 7). The USEPA compiles emissions for the NEI every three years and published the mercury database for 2008 in April 2012.
- Emissions inventory for 2001 for point source mercury emissions throughout California and the United States compiled for the USEPA's Regional Modeling System for Aerosols and Deposition (REMSAD) (USEPA 2008a; USEPA 2008b, Table 1; ICF 2011). See section 6.4.4 and Appendix D for a review of the REMSAD model and inventory development.

The anthropogenic emission inventories and related published literature indicate that mercury emissions from North America and Europe have decreased substantially since 1990, while emissions from Asia have increased:

- Between 1990 and 2000, emissions from North America and Europe decreased by about 40 – 60%, respectively, with continued reductions after 2000. Emissions from the

United States decreased by almost 60% between 1990 and 2005, and by about 40% between 2005 and 2008.

- In contrast, emissions from Asia increased by more than 50% between 1990 and 1995, with smaller increases between 1995 and 2005.
- Emissions from Asia accounted for about 40% (in 1990) to nearly 70% (in 2005) of all global emissions.
- Emissions from North America accounted for about 8% of global emissions in 2005, and emissions from the United States accounted for about 60% of North American emissions.

Some inter-annual variability results from estimation methodology differences as well as the inclusion of additional sources in some years' inventories (Pacyna et al. 2002, 2006, and 2010; Pirrone et al. 2010; AMAP/UNEP 2008; USEPA 2012a). Nonetheless, mercury emissions from North America and Europe have decreased substantially since 1990, while emissions from Asia have increased, based on comparing multiple estimates in published literature.

Half of the increase in Asian emissions between 1990 and 1995 was due to emission changes in China, primarily because of increased demand for electricity and heat and mostly based on coal combustion, according to a 2008 United Nations Environment Programme (UNEP) and Artic Monitoring and Assessment Programme (AMAP) study. The study authors noted that energy demand in the region stabilized between 1995 and 2000, and new power plants were being equipped with emission controls, but emissions from small residential, coal-fueled furnaces continued to grow (AMAP/UNEP 2008).

Almost half of global emissions come from fossil fuel combustion for power and heating (Figure 6.12), per the 2005 global inventory. Other large global sources include artisanal and small-scale gold production, metal production, and cement production. Fossil fuel combustion—especially coal combustion—is also a large source of mercury emissions in the United States, per the USEPA NEI and REMSAD inventories. Other large sources in the United States include cement production, waste incineration, metal production, and the chlor-alkali industry.

California is very different from the nation and the globe in terms of primary emission types (Figure 6.12). Specifically, in California there are very few emissions from coal combustion and no emissions from the chlor-alkali industry. Instead, the major emission types in California include Portland cement production, mobile sources (diesel-powered on-road vehicles and non-road equipment), municipal and hazardous waste incineration, geothermal power production, petroleum refineries, and oil and gas extraction. Some sources, such as chemical manufacturing, nonmetallic mineral mining, and concrete and brick manufacturing, may account for only a couple percent or less of all California anthropogenic emissions (Table D.1 in Appendix D). However, as discussed further in section 6.4.4, these same sources may be locally important to deposition in some areas of California.

Emission sources are not distributed evenly across California. For example, the 2008 emissions inventory for California indicates about 80% of all emissions comes from eight counties: Kern, San Bernardino, Los Angeles, San Diego, and Imperial Counties in southern California, and Sonoma, Contra Costa, Santa Cruz, and Sacramento Counties in northern California (Tables D.1 and D.2 in Appendix D). More than half of all emissions occur in three counties: Kern, San Bernardino, and Sonoma Counties. Section 6.4.4 contains a detailed review of emissions from these areas.

Total reported emissions from California decreased by more than 50% between 2001 and 2008 (Figures 6.13 and 6.14, Table D.1 in Appendix D). Emissions from several California emission sectors decreased, particularly municipal and hazardous waste combustion, fuel combustion associated with energy production and industrial boilers, cement production, and oil and gas production. In addition, only about half as many facilities reported mercury emissions in California in 2008 as in 2001.

The decreasing mercury emission trends observed in California are consistent with nationwide trends (USEPA 2012b). Reductions observed in California emissions result from a suite of reasons that mirror those described by USEPA in its review of nationwide trends in the 2008 National Emissions Inventory report (USEPA 2012b, page 26):

> *The lower emissions in 2008 are due to a combination of methodology differences, state rules, consent decrees, activity levels (e.g., lower cement production in 2008) and reductions that occurred from facilities prior to MACT [Maximum Achievable Control Technology] compliance dates. For EGUs [electric generating utilities], the difference in emissions from 2005 to 2008 is due primarily to the installation of Hg controls to comply with state specific rules and voluntary reductions, and the co-benefits of Hg reductions from control devices installed for the reduction of SO2 and PM as a result of state and federal actions, such as New Source Review enforcement actions. The MATS [Mercury and Air Toxics Standards] rule is expected to reduce mercury by an additional 23 tons by 2016.*
>
> *The 2008 NEI [National Emissions Inventory] is also believed to be lower for some categories due to economic reasons and due to early reductions for some categories. There were facility shut downs and reduced operations at chemical manufacturing facilities and in metals industries. For other categories, a combination of voluntary and state programs has reduced Hg ahead of MACT standards. For gold mines, reductions occurred initially due to a voluntary program developed by EPA Region 9 and Nevada and then further reductions were achieved through a Nevada state regulatory program. In the mercury chlor-alkali industry, facilities have been switching technologies to eliminate Hg emissions from chlorine production. Many switched prior to 2008 and several switched after; therefore, even more reductions from chlor-alkali facilities are expected to be seen in the 2011 NEI. For electric arc furnaces, emissions are lower due to methods of emission estimating.*

The 20 facilities with the highest mercury emissions accounted for about 80% of all facility emissions in California, and the 50 facilities with the highest mercury emissions accounted for about 90% or more of all facility emissions. This was regardless of the number of facilities reporting emissions in each of the annual inventories. Many of the facilities with high mercury emissions are clustered in the northern Coast Ranges northeast of Santa Rosa, San Francisco Bay area, Bakersfield area, and Los Angeles area (Figure 6.15). Emissions from cement manufacturing, geothermal power production, and petroleum industry facilities within the top

50 reporting facilities accounted for about 60 – 80% of all annual statewide facility emissions. These emissions are discussed more in section 6.4.4.

6.4.4 Atmospheric Deposition in California

Mercury can be emitted to the atmosphere as gaseous elemental mercury (Hg^0), divalent mercury compounds in gaseous phase (Hg^2), and divalent mercury compounds in particulate phase (Hg_P). These species represent the oxidation state of mercury, and the gas and particulate phases. Because of their solubility and tendency to attach to particles, Hg^2 species tend to be deposited relatively close to their source, whereas Hg^0 remains in the atmosphere much longer (0.5 to 2 years), contributing to long-range transport. Hg^0 dominates total mercury composition in the atmosphere (greater than 95%) (Schroeder and Munthe 1998; Houyoux and Strum 2011). Hg^0 is eventually oxidized to Hg^2 and readily deposited. Deposition of emitted Hg^2 and Hg_P can directly affect the region of an emission source, although Hg^2 can also be reduced to Hg^0 and enter the global pool.

Deposition of mercury may either occur in wet form (precipitation such as rain, sleet, snow, and dew) or dry form (particulate or gaseous settling). In addition, previously deposited mercury from natural and anthropogenic sources can be re-emitted to the atmosphere from land and water surfaces.

In California, one long-term and several short-term monitoring studies evaluated atmospheric mercury in wet deposition at 13 sites and dry deposition at 7 sites (Figure 6.16, Tables D.3 and D.4 in Appendix D). However, while these monitoring studies provide useful data about specific locations and dates, the data are inadequate to characterize statewide atmospheric deposition patterns. For example, the majority of monitoring locations cluster in central California near the Pacific coast and near Los Angeles; no monitoring data are available for northern inland California, northern and central Sierra Nevada, and southeastern California. In addition, sampling periods of different monitoring studies span a variety of durations between 1985 and 2010, making characterization difficult.

Consequently, staff used the model output from USEPA's REMSAD to characterize atmospheric deposition patterns throughout California. REMSAD is a three-dimensional grid model designed to calculate concentrations of both inert and chemically reactive pollutants by simulating physical and chemical processes in the atmosphere that affect pollutant concentrations (USEPA 2008a). The model simulates the transfer of mercury mass between its different oxidation states and its gas and particulate phases, as well as both wet and dry deposition. The REMSAD model uses "tagging," which allows tracking of emissions through space and time. "Tags" can be individual sources, source types, and source regions, both separately and in combination. REMSAD's annual deposition simulation period is 2001.

Staff used the REMSAD model to characterize atmospheric deposition in California because it was designed specifically to support TMDL development and implementation and because its simulated spatial distribution of mercury deposition is consistent with observed deposition patterns. Additional description of the REMSAD model and comparison of its output to deposition rates observed at different locations in California is in Appendix D.

The REMSAD model output, when combined with emissions inventories, can address key questions about atmospheric deposition stated at the beginning of section 6.4. Each question has its own section below.

How much atmospheric mercury is deposited in California and where does it come from?

About 5,300 kg of mercury were deposited in California in 2001 from local and global emissions, according to the REMSAD model. The REMSAD model estimated deposition from the sum of all sources (Figure 6.17) as well as deposition from:

- Anthropogenic emissions in 2001 from California, other United States, Canada, and Mexico (Figure 6.18)
- Global background emissions in 2000 and re-emissions in 2001 from land and water surfaces of previously deposited mercury, which include both natural and anthropogenic sources from California and elsewhere in the world (Figure 6.19).

The REMSAD model results in Table 6.5 for California and other United States, Canada, and Mexico sources account only for anthropogenic sources of mercury and do not include atmospheric deposition from natural mercury sources.

Results for global and re-emission sources include natural sources. The emissions inventories upon which the global modeling was based indicate natural sources account for approximately 30% of global emissions (Selin et al. 2007; Seigneur et al. 2004; Shia et al. 1999). Consequently, deposition from natural sources in Table 6.5 was calculated as 30% of the deposition from global and re-emission sources.

As summed in Table 6.5, about 10% of mercury deposition in California comes from anthropogenic sources within California, about 60% comes from anthropogenic sources outside of California, and about 30% comes from natural sources. This report refers to anthropogenic sources outside of California as "*global* anthropogenic emissions" because the REMSAD model attributes very little mercury deposition in California to anthropogenic emissions from neighboring states or other North American countries. REMSAD attributes only 0.4%, 0.2%, and 0.002% of deposition to 2001 anthropogenic emissions in the United States (not including California emissions), Mexico and Canada, respectively.

As discussed in the previous section, emissions from California and nationwide anthropogenic sources have decreased since 2001 but increased from Asian and other sources. Chapter 7 evaluates how recent emission changes, and predictions of future changes, could affect atmospheric deposition in California.

Where are there elevated rates of mercury deposition and are they caused by anthropogenic emissions in California or other sources?

Overall, much of California has low atmospheric deposition rates. Areas of very low atmospheric deposition rates are the northernmost coast, central coast, northeastern part of the state, and easternmost part of the state. In some areas, the low deposition rates are associated with wet deposition, and elsewhere they are associated more with dry deposition. Yet there are areas in California with total deposition rates so high they rival peak deposition rates in the eastern

United States, long known for high atmospheric deposition due to emissions from coal-fired power plants and other industrial sources. These general patterns in total, wet, and dry deposition rates across the state are seen in Figures 6.17 and 6.20.

In the southeastern part of the state, elevated (e.g., greater than 20 $g/km^2/year$) mercury deposition is primarily from global background and not California anthropogenic emissions, according to the REMSAD model (Figures 6.17, 6.19 and 6.21). However, in other areas of the state, elevated mercury deposition is attributed to in-state anthropogenic emissions. Several of these areas encompass facilities with emissions tagged by REMSAD because they are the largest emissions in California. These facilities include cement plants, municipal waste incineration (City of Long Beach Southeast Resource Recovery Facility), hazardous waste incineration (Sierra Army Depot), and geothermal power plants (e.g., The Geysers Units 13 and 16) (Figure 6.22). Emissions from these facilities account for about 70% of all California anthropogenic emissions identified in the 2001 REMSAD emission inventory, and about 60% of all deposition attributed by REMSAD to 2001 California anthropogenic emissions.

Where might anthropogenic emissions in California account for a substantial portion of atmospheric deposition?

There were 18 hotspot areas in California in 2001 where California anthropogenic emissions may account for 20% or more of all deposition, according to the REMSAD model (Figure 6.23), with some areas as high as 87%. Although these hotspot areas comprise only about 10% of the total area of the state, about 50% of all atmospheric deposition in California attributed to California anthropogenic emissions occurs in these areas.

The REMSAD model did not tag all emission sources in California, only the very largest. In addition, the model simulates only annual deposition for 2001. As a result, staff reviewed the model results and 2001, 2002, 2005, and 2008 facility emission inventories to determine where non-tagged emissions may contribute to hotspot areas and to evaluate how facility emissions have changed since 2001 (Tables 6.6 through 6.10). Information about how emissions have changed since 2001 is incorporated into the allocation calculations in Chapters 7 and 8. This review indicates:

- All but three facility emissions in the 2001 deposition hotspot areas substantially decreased between 2001 and 2008, with decreases ranging from about 30 to 100 percent. The three hotspot areas that did not appear to experience substantial emission reductions are Sacramento, San Diego, and the Carquinez Strait.
- Five of the 18 deposition hotpots were likely caused by emissions from a single facility within the hotspot areas. However, the facilities associated with these five 2001 deposition hotspots did not report any emissions in 2008, indicating the following areas may no longer be hotspots: Honey Lake Valley, Monterey County Southeast, Sierra Nevada foothills (SNF) near Englebright Lake, SNF near New Melones Reservoir, and SNF near North Fork American River.
- Cement plants were likely the primary emission source for four of the 2001 deposition hotspot areas (East Kern County, San Bernardino County Southwest, San Francisco Bay Area, and Santa Cruz Area), and likely contributed to several other hotspot areas.

- Geothermal power plants were likely the primary emission source for two hotspot areas: Coast Ranges near The Geysers and Imperial Valley near Salton Sea.
- Oil and gas production was likely the primary emission source for four of the 2001 deposition hotspot areas: Kern County West, Monterey County Southeast, San Luis Obispo County Southeast, and Santa Barbara Area. In one of these hotpot areas, Monterey County Southeast, there were no emissions reported from oil and gas production in the 2008 inventory.
- Facility emissions in the Carquinez Strait area increased by 7% between 2001 and 2008. Petroleum refining and chemical manufacturing were likely the primary emission sources.
- Three of the 2001 deposition hotspot areas are likely affected by a variety of emission sectors rather than just one or two: Los Angeles, Sacramento, and San Diego areas.
- The City of Long Beach Southeast Resource Recovery Facility (SERRF) and cement plants in the Los Angeles region accounted for about 40% and 30% of all facility emissions in the 2001 inventory, respectively. The remaining 30% of emissions came from a variety of industrial and municipal sources. Reported facility emissions in the Los Angeles area decreased by 63% between 2001 and 2008, and emissions from the Long Beach SERRF decreased from 472 kg/year to 60 kg/year between 2001 and 2008, a reduction of 87%.
- Facility emissions in the Sacramento area increased by almost 20% between 2001 and 2008, with the majority of emission from cremation, nonmetallic mineral mining, and concrete and brick manufacturing.

What are the emission sources that contribute most to deposition to mercury-impaired reservoirs?

Controlling anthropogenic emissions in California should reduce the amount of mercury deposited in some reservoirs. Specifically, the REMSAD model indicates that 69 of the 74 2010 303(d)-listed reservoirs or their watersheds are within the deposition footprint of California anthropogenic emissions, where deposition attributed to California anthropogenic emissions exceeds 0.5 g/km^2/year (Figure 6.17 and Table 6.11).

Reducing California anthropogenic emissions could make a substantial, measurable reduction in atmospheric deposition to some reservoirs. Specifically, the REMSAD model indicates that 21 of the 74 303(d)-listed reservoirs or their watersheds are in areas where California anthropogenic emissions may account for 20% or more of all deposition, with some as high as 83% (Table 6.11).

REMSAD attributes more than 50% of atmospheric deposition to California anthropogenic emissions at El Dorado Lakes (83%), Davis Creek Reservoir (73%), Indian Valley Reservoir (57%), Puddingstone Reservoir (53%), and Lake Herman (52%) (Table 6.11). Emissions from municipal waste incineration, geothermal power production, cement plants, and petroleum refineries in California are likely the most important modern anthropogenic contributors to atmospheric deposition to these reservoirs and their watersheds (Tables 6.8, 6.9, 6.12 and 6.13). [Note: two of these reservoirs—Davis Creek Reservoir and Lake Herman—had historic mercury and gold mining operations in their watersheds; consequently, mining waste inputs to these reservoirs may be more substantial than inputs from modern atmospheric deposition.] Table 6.12 identifies the California emissions hotspot areas intersected by the reservoirs and their watersheds and Table 6.13 provides the percent of deposition attributed to California anthropogenic sources tagged by the REMSAD model. Tables 6.6 through 6.9 provide reviews of 2001 model results for deposition characteristics of the hotspot areas and 2001-2008 facility emissions within or adjacent to the hotspot areas.

Are there any mercury-impaired reservoirs where atmospheric deposition is the primary anthropogenic mercury source?

Atmospheric deposition is the dominant anthropogenic source to 29 of the 74 303(d)-listed mercury-impaired reservoirs in California (Table 6.12). Atmospheric deposition is the dominant anthropogenic mercury source to reservoirs where there are few or no modern point sources, historic mercury mines, or other mining activities that used mercury in reservoir watersheds. At 12 of these 29 reservoirs, atmospheric deposition associated with California anthropogenic emissions may account for more than 20% of all REMSAD modeled deposition. Where the deposition rates are particularly high and mostly attributed to California anthropogenic emissions—El Dorado Park Lakes, Indian Valley Reservoir, and Puddingstone Reservoir—we expect to see a reduction in fish methylmercury levels if California emissions are reduced.

Deposition from global anthropogenic emissions may be the primary anthropogenic source to the remaining 17 mercury-impaired reservoirs. Anthropogenic emissions from sources outside of California (global anthropogenic emissions) are the dominant anthropogenic mercury source to reservoirs where California anthropogenic emissions account for less than 20% of the REMSAD modeled deposition and there are few or no modern point sources, historic mercury mines, or other mining activities that used mercury in reservoir watersheds. Consequently, implementation of global treaties will be required to make substantial reductions in atmospheric deposition at these reservoirs.

Recommendations

Staff recommends the following baseline values be used to characterize current atmospheric deposition in California. These values will be used to develop allocations in Chapters 7 and 8.

- Natural sources: 1,400 kg/yr
- California anthropogenic: 680 kg/yr
- Global anthropogenic: 3,200 kg/yr

6.5 Urban Runoff

Evaluating sources of mercury in urban runoff, along with identifying where urbanized lands are present, helps us address several key questions:

- How much mercury in urban runoff comes from controllable sources?
- Do urbanized lands contribute substantially to mercury-impaired reservoirs?

- How much of urbanized lands upstream of mercury-impaired reservoirs are regulated by NPDES permits?

We concluded the following from this evaluation:

- Atmospheric deposition from local and global emissions is the primary source of mercury in urban runoff. In addition, improper disposal and illegal dumping of mercury-containing products can make direct contributions to stormwater conveyance systems via runoff, as well as indirect contributions via emissions to the atmosphere and subsequent deposition to and runoff from urban watershed surfaces.
- Mercury in urban runoff resulting from local use of mercury-containing products is expected to decrease to almost zero because of the many bans on new mercury use in California and implementation of institutional controls and best management practices.
- Overall, urbanized lands are not substantial contributors of mercury to impaired reservoirs identified on the 2010 303(d) List. With only three exceptions, there is very little urbanized land upstream of these mercury-impaired reservoirs. The three exceptions are Beach Lake, Puddingstone Reservoir, and El Dorado Park Lakes, where developed lands comprise about 20 – 30% of their watersheds.

The following sections provide our evaluation of the above questions.

6.5.1 Mercury in Urban Runoff

Urban runoff includes precipitation-induced stormwater runoff and irrigation runoff from landscaped areas. Runoff transports mercury attached to suspended sediment to surface waters which in turn transports mercury-contaminated sediment to reservoirs.

Sediment mercury concentrations in urban runoff from California’s major urban areas often exceed the modern soil background levels reviewed in section 6.2, with lower mercury concentrations in less densely populated cities like Tracy, and higher concentrations in more densely populated and industrial regions like Los Angeles (Table 6.14). This is consistent with McKee and others’ 2006 review of world soils that found a continuum from remote areas with low concentrations gradating through urban areas with little industry to industrial areas with very high soils concentrations, with concentrations varying by three to four orders of magnitude. In general, the highest concentrations are found in areas closer to industry and known point sources.

Mercury in urban runoff originates from atmospheric deposition, local urban sources, and erosion of soils that naturally contain mercury, with atmospheric deposition being the dominant source (CDEP 2007; Davis et al. 2012; Eckley et al. 2008; Eckley and Branfireun 2008; Fulkerson et al. 2007; McKee et al. 2006; MPCA 2007; and NJDEP 2009). As discussed in section 6.4, atmospheric deposition comes from global and local emissions, from both natural and anthropogenic sources.

Atmospheric emissions from local urban sources contribute mercury to urban runoff. These include point sources such as waste incinerators and cement plants, and nonpoint sources such as exhaust from diesel powered on-road vehicles and non-road equipment, and atmospheric losses during handling and disposal of dental amalgam and laboratory reagents and sample preservatives. In addition, more atmospheric deposition is transported by runoff in urban areas than undeveloped areas because urbanization increases the amount of impervious surfaces, which do not absorb water or trap pollutants like soil does. As a result, atmospheric mercury deposited in urban areas has a much greater chance of being quickly transported to downstream waters. In contrast, recent studies indicate as little as 1% of atmospheric deposition may be transported from undeveloped watersheds to downstream water bodies (Tate et al. 2011; Harris et al. 2007).

In addition, mercury was, and still is, used in many household and commercial products, as well as historical and ongoing industrial processes. The main uses include instruments, switches, thermostats, fluorescent lighting, batteries, and electronics. Additional uses include paints, dental amalgam, and laboratories. The improper handling, inadequate disposal, and illegal dumping of mercury-containing products can make direct contributions to stormwater conveyance systems via runoff, as well as making indirect contributions via emissions to the atmosphere and subsequent deposition to and runoff from urban watershed surfaces. Industrial areas, auto-recyclers, demolition and remodeling sites, residential and commercial dumpsters, and illegal dumps near or in creeks—anywhere mercury is spilled from a broken product—can become source areas that contribute mercury directly or indirectly to urban runoff.

6.5.2 Location of Urbanized Lands

The high population regions in California are downstream of all but a few of the 74 303(d)-listed reservoirs; with only 3 exceptions, there is very little urbanized land upstream of these mercury-impaired reservoirs (Figure 2.6 in Chapter 2). Urbanized land is evaluated herein as a proxy for one or more MS4s service or jurisdictional areas because map data for urbanized land is readily available; map data is not readily available for MS4s service or jurisdictional areas. Reservoir watershed area evaluated herein is the immediate reservoir watershed; the watershed area does not extend upstream above any dams on tributaries.

Staff used two sources of information to determine where and how much urbanized land (including major roads) is present throughout the state and in each 303(d)-listed reservoir watershed:

- 2006 National Land Cover Database (NLCD) produced by the Multi-Resolution Land Characterization (MRLC) Consortium (MRLC 2011; Fry et al. 2011)
- 2010 Census TIGER/Lines Shape files produced by the U.S. Census Bureau (USCB 2012a and 2012b)

The 2006 NLCD is a 16-class land cover classification scheme that has been applied consistently across the conterminous United States at a spatial resolution of 30 meters and is based primarily on 2006 satellite data. The NLCD classifies developed areas where there is a mixture of constructed materials and vegetation into four categories:

- Open space: Impervious surfaces account for less than 20% of total cover. Open spaces commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.

- Low and medium density: Impervious surfaces account for 20 – 50% and 50 – 79%, respectively, of total cover. Low and medium density developed areas most commonly include single-family housing units.
- High density: Impervious surfaces account for 80 – 100% of total cover. These areas include highly developed areas where people reside or work in high numbers and include apartment complexes, row houses, commercial/industrial areas, and major roads.

For the 2010 Census, the Census Bureau classified as urban all territory, population, and housing units within "Urbanized Areas" (UAs) and "Urban Clusters" (UCs). An Urbanized Area consists of densely developed territory that contains 50,000 or more people. An Urban Cluster consists of densely developed territory that has at least 2,500 people but fewer than 50,000 people. The UAs and UCs may encompass a variety of NLCD land cover classifications, including undeveloped areas.

The majority of Census-designated Urbanized Areas and Urban Clusters throughout California are downstream of reservoirs (Figure 2.6 in Chapter 2). Correspondingly, more than half of the 74 reservoirs on the 2010 303(d) List have virtually no area (<0.1%) classified as UA or UC within their watersheds (Figure 6.24A). Two of the 303(d)-listed reservoirs—Shadow Cliffs and Lafayette—have watersheds entirely within a UA or UC but, as discussed below, have very little developed land. In contrast, more than 50% of El Dorado Park Lakes, Puddingstone Reservoir, and Beach Lake watersheds are encompassed by a UA or UC, and they are more than 20% developed.

Similarly, the NLCD classifies very little of the land in most 303(d)-listed reservoir watersheds as developed, and much of the developed land is open space (Figure 6.24B). Correspondingly, more than three quarters of the 303(d)-listed reservoirs have very little developed area (<1% of their watersheds with impervious area greater than 20%).

Accordingly, urbanized lands are not substantial contributors of mercury to impaired reservoirs. With only 3 exceptions, there is very little urbanized land upstream of 303(d)-listed reservoirs. The three exceptions are Beach Lake, Puddingstone Reservoir, and El Dorado Park Lakes, where developed lands comprise about 20 – 30% of their watersheds. Specifically, Beach Lake in the greater Sacramento region has 32% of its watershed developed, and Puddingstone Reservoir and El Dorado Park Lakes in the greater Los Angeles region have 32% and 24%, respectively. Beach Lake is in the Bufferlands Preserve but its watershed (Morrison Creek) includes residential and commercial areas south of Sacramento. Similarly, Puddingstone Reservoir is located in the Bonelli Regional Park but its watershed includes residential and commercial areas of Claremont, La Verne, Pomona, San Dimas, and the County of Los Angeles (USEPA 2012e). In contrast, the El Dorado Park Lakes are a chain of six small lakes within El Dorado Regional Park in the county of Los Angeles and do not have any organized storm drain network nor any permitted point sources in their watershed (USEPA 2012).

6.5.3 Urban Runoff Regulated by NPDES Permits in Impaired Reservoir Watersheds

Most of the 303(d)-listed reservoir watersheds have very little urbanized land encompassed by NPDES permit areas because, as described in the previous section, only three 303(d)-listed reservoirs have watersheds with substantial development.

NPDES permits adopted by the Water Boards regulate several different categories of urban runoff:

- Phase I MS4 area-wide permits: These are individual permits for discharges from municipal separate storm sewer systems (MS4s) that serve medium (100,000 to 250,000 people) and large (>250,000 people) municipalities. These are called Phase I MS4 permits because MS4 permits were issued in two phases and the medium and larger municipalities were regulated first. There are currently 21 Phase I permits issued for metropolitan areas throughout the state.
- Phase II small MS4 general permit (NPDES No. CAS000004): This statewide permit provides coverage for small MS4s not encompassed by individual area-wide permits that are located within Census-based Urbanized Areas and other areas with a high population and population density (population >10,000 and density >1,000 residents per square mile). The permit also provides coverage for small MS4s that discharge to Areas of Special Biological Significance as defined in the California Ocean Plan.
- Caltrans permit (NPDES No. CAS000003): This statewide permit applies to discharges from the California Department of Transportation (Caltrans) network of highways and road facilities. The state highway system and other Caltrans properties discharge either directly to surface waters or indirectly through municipal stormwater conveyance systems.
- General stormwater permit for construction activities (NPDES No. CAS000002): This statewide permit regulates discharges from projects that disturb one or more acres of soil, or that disturb less than one acre but are part of a larger common plan of development.
- General stormwater permit for industrial activities (NPDES No. CAS000001): This statewide permit regulates discharges associated with ten broad categories of industrial activities, including landfills, sewage treatment plants, manufacturing, transportation, mining, oil, gas, hazardous waste treatment, recycling, steam electric generation, and other light industrial facilities.

Appendix E summarizes the number of NPDES permittees in each of the 303(d)-listed reservoir watersheds.

Most of the 303(d)-listed reservoir watersheds have very little urbanized land regulated by Phase I and II MS4 permits. For example, 49 of the 74 reservoirs on the 2010 303(d) List have no developed area regulated by MS4 permits within their watersheds. Of the 303(d)-listed reservoirs that have some portion of a permitted MS4 within their watersheds, only 2 have watersheds more than 20% developed: Beach Lake (32%) in the greater Sacramento region, and Puddingstone Reservoir (32%) in the greater Los Angeles region.

Similarly, most of the 303(d)-listed reservoir watersheds have very few (given their immense area) active construction and industrial permittees. The Beach Lake and Puddingstone Reservoir watersheds by far have the highest density of construction and industrial permittees.

These findings provide further indication that, with only a few exceptions (e.g., Beach Lake, Puddingstone Reservoir, and El Dorado Park Lakes), urbanized lands are not substantial contributors of mercury to impaired reservoirs.

6.6 Municipal and Industrial Facility Discharges

This section provides an overview of municipal and industrial facility discharges throughout the state, describes mercury concentrations in facility discharges, identifies facilities that discharge to or upstream of 303(d)-listed reservoirs, and describes the magnitude of their discharges. These evaluations address the key question: Where could facility discharges contribute substantially to elevated fish methylmercury concentrations in reservoirs?

The following sections evaluate the above question based primarily on facility information and mercury concentration data available in the California Integrated Water Quality System (CIWQS) and USEPA databases, supplemented by information in NPDES permits and published literature. The following sections focus on discharges from facilities with individual permits. As explained in Appendix F, discharges from facilities regulated by general permits are considered negligible.

Staff concluded the following from this evaluation:

- Facility dischargers are not evenly distributed across the state. Statewide, less than 10% of statewide facilities are upstream of 303(d)-listed reservoirs, and only about 1% of the statewide permitted discharge volume is upstream of reservoirs.
- More than half (66%) of 303(d)-listed reservoirs do not have any individually permitted facility discharges in their watersheds.
- Of the 25 303(d)-listed reservoirs with at least 1 facility discharge in their watersheds, only 1 (Beach Lake) may receive substantial inputs from facility discharges. For the other 24 reservoirs, facility design flows comprise less than 1% of reservoir inflows, and the facilities contribute only a tiny fraction of mercury contributed by atmospheric deposition. Facility effluent mercury loads (based on design flows to account for future growth) for these 24 reservoirs are less than 5% of mercury loads from atmospheric deposition.

6.6.1 NPDES-Permitted Facilities in California

There are over 500 individual NPDES permits for municipal wastewater treatment plants (WWTPs), industrial dischargers, and other types of facilities throughout California. Industrial dischargers include petroleum refineries, chemical plants, manufacturing facilities, saw mills, and groundwater remediation facilities. Other types of facilities include power plants, fish hatcheries, drinking water treatment plants, and groundwater cleanup sites.

Municipal WWTPs are by far the most numerous type of facility; about 50% of all facilities in the state are municipal WWTPs (Figure 6.25). However, power plant discharges (the majority of which are noncontact cooling water with no wastewater added) make up about 70% of discharge volume. Municipal WWTP discharges comprise about 20% of discharge volume statewide.

Facility dischargers are not evenly distributed across the state. Figures 6.26 and 6.27 summarize the number of dischargers and total permitted discharge amount (i.e., design flows) grouped by receiving water location. Most discharges are downstream of reservoirs and flood control basins. Less than 10% of statewide facilities are upstream of 303(d)-listed reservoirs and only about 1% of statewide permitted discharge volume is upstream of reservoirs. This is not surprising given, as described in the previous section, most 303(d)-listed reservoirs have very little urbanized area in their watersheds.

Mercury from Municipal WWTPs

Municipal wastewater treatment plants that discharge to inland waters, bays, and estuaries in California provide either secondary or tertiary treatment. Secondary treatment generally includes settling, filtration, and biological treatment. Some plants also provide advanced secondary treatment, which removes additional solids. Tertiary treatment generally includes additional physical, chemical, and biological treatments to remove nutrients (phosphorus and nitrogen), organic matter, suspended solids, and toxic materials, and to disinfect the wastewater. Removing additional solids removes additional pollutants, like mercury, that adhere to particles. Municipal wastewater treatment plants remove over 90% of mercury in their influent (AMSA 2000). The primary sources of mercury in municipal wastewater are human waste and medical and dental facilities (Palo Alto RWQCP 1999). Nationwide, about half the mercury that enters municipal wastewater treatment systems comes from dental offices that do not use amalgam separators (USEPA 2014).

Staff compiled effluent mercury concentration data for 107 municipal WWTPs during a five-year period, 2008 to 2013. The compilation of 2,016 results includes only samples collected using “ultra clean” methods (e.g., EPA Method 1631) from WWTPs still discharging to inland surface waters in 2013. Figure 6.28 and Table 6.15 summarize the effluent concentration data. All compiled effluent mercury data are in Table Z.4 in Appendix Z, which is provided as a Microsoft Excel file.

Mercury from Other Discharge Types

Mercury concentrations in industrial and other types of discharges depend on the types of activities in which these dischargers engage. Therefore, staff compiled effluent mercury concentration data for 47 different (non-WWTP) discharges for a longer period, 2000 to 2013. The compilation includes facilities that no longer discharge to surface waters because much fewer data are available for industrial dischargers than municipal WWTPs. However, the compilation excludes effluent data for power plants and fish hatcheries with discharges primarily composed of noncontact cooling water or other surface ambient water derived from the same water bodies as their receiving waters. The compilation of 409 results includes only samples collected using “ultra clean” methods (e.g., EPA Method 1631). All compiled effluent mercury data are in Appendix Z. In addition, staff used a San Francisco Bay Regional Water Quality

Control Board analysis of petroleum refinery effluent mercury data because it was more comprehensive than what staff could accomplish with CIWQS data (SFBRWQCB 2001).

Staff separated the effluent data for the industrial and other dischargers into four significantly different groups (Kruskal-Wallis test, $p < 0.001$): petroleum refineries; municipal combined stormwater sewer systems; municipal WWTPs; and all other facilities. Each of these groups has mercury concentrations statistically different from municipal WWTP effluent mercury concentrations. Figure 6.28 and Table 6.15 summarize the effluent concentration data. Combined stormwater sewer systems and petroleum refineries have significantly higher effluent mercury concentrations than other types of facilities.

Comparison of NPDES Facility Contributions to Other Mercury Sources

Statewide, mercury loading to inland waters from NPDES facility dischargers is trivial compared to mercury loading by sources like atmospheric deposition. For example, the statewide annual mercury load from NPDES facilities is only 23 kg/year (Table 6.15). (Calculation: sum of design flows for all facilities that discharge to inland waters (except power plants and fish hatcheries that discharge primarily ambient surface water) multiplied by median mercury concentration for each of the four before-mentioned facility groups.) This 23 kg/year is only 0.4% of the 5,300 kg/year of mercury deposited in California in 2001 (per USEPA's REMSAD model), and only 3% of the modelled 680 kg/year deposited by California anthropogenic emissions (see section 6.4 for more information about atmospheric deposition). Even if local emissions are reduced by half, as predicted by emission reductions since 2001, facility discharges would still comprise only about 0.3% of total statewide atmospheric deposition and 4% of deposition that could be attributed to local emissions.

Nonetheless, as observed in the previous section, facility discharges are not evenly distributed across the state. Consequently, the next section evaluates NPDES discharges within the 303(d)-listed reservoir watersheds.

6.6.2 Facility Discharges in Impaired Reservoir Watersheds

Of the 74 reservoirs on the 2010 303(d) List, 49 (about two thirds) have no facility discharges regulated by individual NPDES permits, while the remaining 25 contain at least 1 facility discharge regulated by an individual NPDES permit (Figure 6.29). There are 44 facilities with individual NPDES permits that discharge upstream of 303(d)-listed reservoirs and 3 that discharge directly to a 303(d)-listed reservoir:

- The Chester Public Utilities District WWTP discharges to Almanor Lake;
- The Castaic Power Plant discharges to Castaic Lake and Pyramid Lake; and
- The William Warne Power Plant discharges to Pyramid Lake.

About one-third of the facilities discharge water within five miles upstream of a 303(d)-listed reservoir. In contrast, almost half of the facilities discharge from 20 to more than 100 miles upstream of a 303(d)-listed reservoir.

Municipal WWTPs are the most numerous type of facility; about half of all facilities that discharge to or upstream of 303(d)-listed reservoirs are municipal WWTPs (Figure 6.30). However, power plant discharges and groundwater treatment facilities combined make up about 60% of the discharge volume, whereas municipal WWTP discharges comprise about 30% of the discharge volume.

More than 70% of municipal and industrial facilities have permitted design flows less than 1 million gallons per day (MGD) and of those, about one third have flows less than 0.2 MGD. Facilities that discharge greater than 1 MGD include 3 hydroelectric power plants, 2 groundwater remediation facilities, 3 municipal wastewater treatment plants, and 1 mine drainage treatment facility. Table G.1 in Appendix G identifies the facilities, their design flows, receiving waters, and effluent total mercury concentrations.

In general, NPDES facilities are small to insignificant contributors of mercury to 303(d)-listed reservoirs. Facility discharges may be a substantial contributor to only one 303(d)-listed reservoir, Beach Lake, which receives water from the Morrison Creek watershed in the greater Sacramento region. The following paragraphs describe how facility discharges were assessed relative to other reservoir inputs.

Comparison Procedure

As noted at the beginning of this chapter, discharges from most types of NPDES-permitted facilities tend to be very low in suspended solids. As a result, this source assessment evaluates NPDES-permitted facility discharges in terms of total recoverable mercury in facility effluent. Point source discharges are considered a small contribution if the loading or cumulative loading of all point sources to the receiving water are expected to account for a small or negligible portion of total mercury loadings, according to USEPA's Guidance for Implementing the January 2001 Methylmercury Water Quality Criterion (USEPA 2010). USEPA's screening tool, "Mercury Maps: A Quantitative Spatial Link between Air Deposition and Fish Tissue," considered point sources to be significant if they contributed greater than 5% of loading to a water body (USEPA 2001b).

However, estimates of total annual mercury loading into each reservoir from all point and nonpoint sources are not available. Consequently, this assessment evaluates the significance of NPDES facility discharges in two alternate ways:

(1) Compare the sum of facility discharge volumes in a given 303(d)-listed reservoir watershed to annual and dry season reservoir inflows. Facility discharges are considered insignificant if the sum of their design flows is equal to or less than 1% of reservoir annual <u>or</u> dry season inflows. Use of facility design flows rather than current flows is more conservative and takes into account potential future growth. Similarly, use of 1% rather than 5%, as suggested by USEPA, provides a conservative assessment.

(2) Compare the sum of annual facility effluent mercury loads calculated using design flows in a given 303(d)-listed reservoir watershed to the REMSAD modelled annual atmospheric deposition to each reservoir. (Load calculations do not include flow from ambient water intakes for power plants and fish hatcheries.) Facility discharges are considered insignificant if the sum of their effluent loads is equal to or less than 5% of the annual atmospheric

deposition. Use of facility design flows rather than current flows is more conservative and takes into account potential future growth. In addition, comparing facility effluent mercury loads to atmospheric deposition alone is more conservative than comparing to the sum of all possible sources (e.g., inputs from mine waste and watershed soils).

In addition, for method (2), atmospheric deposition to a given reservoir was calculated in two ways: (a) as the sum of modelled deposition direct to the reservoir water surface plus deposition to the watershed (as was done by other USEPA-approved statewide TMDLs, such as the Northeast Regional and Minnesota mercury TMDLs [CDEP 2007; MPCA 2007]), and (b) as the sum of modelled deposition direct to the reservoir water surface plus 10% of the deposition to the watershed. This second atmospheric deposition calculation incorporates a 10% runoff coefficient for the watershed (i.e., assumes 90% of deposited mercury is not immediately transported downstream to reservoirs). This estimated runoff coefficient is appropriate given most 303(d)-listed reservoir watersheds have little development and hence little impervious surface. Mercury runoff coefficients for watersheds with little or no urbanized land vary between 1% and 30% (Dolan 1993; Grigal 2002; Lorey and Driscoll 1999; Mason et al. 1994; Quemerais et al. 1999; Tsai and Hoenicke 2001; Tate et al. 2011).

Results of Comparison

Beach Lake is the only 303(d)-listed reservoir for which facility discharges may comprise more than 1% of reservoir inflows. Beach Lake is also the only 303(d)-listed reservoir for which facility discharges may comprise more than 5% of atmospheric deposition loading to its watershed (Table G.2 in Appendix G). The exceedance of the 1% and 5% thresholds for flow and loading are caused by high facility design flows compared to reservoir inflow rather than high effluent mercury concentrations. There are four groundwater treatment facilities that discharge to Morrison Creek upstream of Beach Lake. The facility design flows range from 0.4 to 6.3 MGD. No effluent mercury data are available for the facilities, but effluent mercury concentrations observed at other groundwater treatment facilities are very low, ranging from less than the method detection limit (0.2 nanograms per liter (ng/L)) to 19 ng/L with a median of 0.9 ng/L (6 facilities, n = 22). The 95th percentile concentration (8 ng/L) was used in the facility load estimates for Beach Lake to account for uncertainty given the lack of data specific to facilities in the Morrison Creek watershed (see Table G.1).

The assessment for Beach Lake was particularly conservative for several reasons. Beach Lake receives inflows from three sources: a canal that diverts water from Morrison Creek during the dry season, groundwater from a high water table, and inundation by backwater from the Beach Lake dike on Morrison Creek downstream of Beach Lake during the wet season (Carollo Engineers 2000). The annual and dry season inflow estimates for Beach Lake do not take into account the inputs from groundwater and backwater inundation. In addition, the inflow estimates assume that all water that flows down Morrison Creek is routed through Beach Lake, versus just a portion of the water via canal. Consequently, the proportion of inflows attributed to facility discharges is almost certainly over-estimated. Hence, facility discharges might only exceed the 1% threshold during the dry season (see Chapter 7 for more discussion.)

Nonetheless, as illustrated in Figure 6.31, the assessment of facility design flows is an adequate surrogate for the assessment of loads to determine whether facilities make significant mercury contributions to reservoirs. The watershed sums of facility design flows as a percent of annual and dry season reservoir inflows are all less than 1% where facility mercury loads are less than 5% of atmospheric deposition loads.

It is not surprising that only 1 303(d)-listed reservoir may receive substantial mercury inputs from facility discharges. As noted in the previous Urban Runoff section, only 3 303(d)-listed reservoirs have watersheds with substantial development: Beach Lake in the Sacramento region, and Puddingstone Reservoir and El Dorado Park Lakes in the Los Angeles region. No facilities with individual NPDES permits discharge to or upstream of El Dorado Park Lakes and Puddingstone Reservoir, however.

6.7 Other Potential Sources

Other potential mercury sources could include groundwater, spring inputs, coastal fog, and water imports. In addition, human activities can disturb and mobilize mercury in naturally mercury-enriched soils as well as in mine waste at upland and floodplain locations, causing transport to creeks and reservoirs or emission to the air.

6.7.1 Groundwater

For some reservoirs, groundwater may be an important source of mercury. For example, USEPA (2012) determined that the northern four lakes in the El Dorado Park Lakes system receive supplemental water from one groundwater well. Total mercury concentrations in the supplemental groundwater were highly elevated and ranged from 131 ng/L to 142 ng/L. The TMDL for El Dorado Park Lakes determined the majority (about 74%) of mercury loading to the northern lakes originates from groundwater. Similarly, a recent study at two sites on the central California coast found that mercury contributions from submarine groundwater were greater than net atmospheric mercury inputs for waters in nearby San Francisco Bay (Black et al. 2009). Groundwater mercury contribution could be a source to Beach Lake. Carollo Engineers (2000) noted that Beach Lake is fed in the dry season by a high water table.

Staff was unable to locate information about use of groundwater to supplement reservoirs elsewhere, or additional mercury concentration data for groundwater elsewhere in the state (other than industrial remediation sites). As a result, staff could not determine if local water tables and groundwater supplements could be an important source to some reservoirs. Reservoir managers, particularly for very small reservoirs such as El Dorado Park Lakes, could consider monitoring mercury concentrations in any supplemental water obtained from groundwater to quantify groundwater mercury contributions.

6.7.2 Springs

Springs may be another natural source of mercury to reservoirs in California. Mercury concentrations in spring water are typically low. For example, the median mercury concentration for 51 Coast Ranges springs sampled by Central Valley Regional Water Quality Control Board staff in 2006 was 1 ng/L (Louie, unpublished data), and the median concentration for Mill Creek, a spring-dominated creek that drains the Lassen Volcanic National Park in the Cascade Range, was 6 ng/L (SRWP 2004; Louie et al. 2008).

However, some springs may have relatively high mercury concentrations, particularly those that occur in mercury-enriched marine sedimentary and volcanic geologic formations. Central Valley Water Board staff sampled three springs in the Coast Ranges that had mercury concentrations ranging from 176 ng/L to almost 3,500 ng/L, and mercury concentrations in Mill Creek, which drains a portion of the Lassen Volcanic National Park, ranged as high as 400 ng/L. Inadequate information is currently available about spring location and flows throughout California to characterize the potential magnitude of spring contributions to 303(d)-listed reservoirs.

6.7.3 Coastal fog

Weiss-Penzias and others (2012) recently observed high levels of mercury in central California's coastal fog. They observed total mercury and methylmercury concentrations in coastal fog around the Monterey Bay in June – August 2011 that were six- and thirty-fold higher, respectively, than total mercury and methylmercury concentrations in rain water from March – June 2011. They estimated that fog water deposition could account for 7 – 42% of total mercury and 61 – 99% of methylmercury in total atmospheric deposition (fog, rain, and dry deposition).

Humidity and fog were considered by the REMSAD model described in section 6.4.4 (e.g., in assessing dry deposition), but deposition attributed to coastal fog and fog in other regions was not “tagged” and tracked separately from other small sources by the model (Atkinson 2012 pers. comm.); only deposition attributed to the largest emissions in California were tracked by the model. Thus, inadequate data are available to characterize the potential magnitude of coastal fog’s contribution to 303(d)-listed reservoirs.

6.7.4 Water imports

Numerous reservoirs in California receive water conveyed from outside the reservoir watersheds by state, federal, and other water projects. Some reservoirs receive water imported from neighboring watersheds while others receive water from distant regions of the state (see Table 6.16). Twenty-one of the 303(d)-listed reservoirs receive at least some water from outside their watersheds, and nine of these receive a large amount or almost all of their water from outside their watersheds. The outside water supplies all originate from watersheds upstream of 303(d)-listed reservoirs. Consequently, mercury sources in these watersheds are included in the geographic scope of the source assessment provided in this chapter and are addressed by the allocations and implementation plan described in Chapters 8 and 9.

6.7.5 Anthropogenic erosion

Human activities can disturb and mobilize mercury naturally occurring in soils and geologic formations as well as in mining waste at upland and floodplain locations, causing transport to creeks and reservoirs or emission to the air. Upland activities that could mobilize mercury-enriched material include timber harvesting, road construction, grading, and off-highway vehicle use. Floodplain and in-channel activities that could mobilize mercury-enriched material could include bridge and road construction, reservoir and dam maintenance, aggregate mining, development, and riparian and wetland restoration projects.

Although inadequate data are available to characterize the potential magnitude of contribution to 303(d)-listed reservoirs from these activities, there are known management practices effective at reducing those contributions (Chapters 7 and 10). In general, erosion control of watershed soils is unlikely to change reservoir sediment mercury concentrations. However, erosion control of mercury-contaminated hotspots, such as mining waste is discussed in section 6.3.

Another in-channel activity that could mobilize mining waste is suction dredging. Use of self-contained underwater breathing apparatus (SCUBA) and portable suction dredges with built-in air compressors to supply air to divers allows individuals to use suction dredges underwater like vacuum cleaners to excavate sediment and recover gold from rivers and streams. A recent USGS study found that suction dredging has the potential to expose and transport mercury in river channels that would not have otherwise been mobilized by natural storm disturbances (Fleck et al. 2011).

California Department of Fish and Wildlife (DFW) issued on average about 3,650 suction dredge permits per year for 15 years prior to the current moratorium established by Senate Bill 670, which took effect in August 2009. Prior to the moratorium, suction dredging took place upstream of several 303(d)-listed reservoirs (DFW 2011). Assembly Bill 120 previously established an end date for the current moratorium of June 30, 2016, but that end date was recently removed from law. Suction dredging activities may need to be further evaluated if any suction dredge permitting program is adopted in the future.

6.8 Source Comparison for 303(d)-Listed Reservoirs

Mercury sources are not evenly distributed across the state. Consequently, 303(d)-listed reservoirs have different suites of sources that contribute to their impairment. Table 6.17 and Figure 6.32 identify the source combinations that contribute to each of these reservoirs.
To summarize:

- Mining waste is the primary anthropogenic mercury source to 14 (19%) of the 74 reservoirs on the 2010 303(d) List, as indicated by their extremely elevated sediment mercury concentrations (where sediment data are available), the very high density of historic mine sites in their watersheds, and few-to-no point sources in their watersheds.
- In a separate set of reservoirs, both mining waste and atmospheric deposition are the primary anthropogenic sources to 24 (32%) of the reservoirs, as indicated by their moderate-to-low sediment mercury concentrations (where sediment data are available), moderate-to-high density of historic mine sites in their watersheds, and few-to-no point sources in their watersheds.
- Atmospheric deposition may be the only substantial anthropogenic source to 25 (34%) of the 74 reservoirs on the 2010 303(d) List, and air emissions from outside of California may be the only substantial anthropogenic source to more than half of these.
- The four northernmost lakes within El Dorado Park receive substantial mercury from supplemental groundwater in addition to atmospheric deposition.
- NPDES-permitted facility discharges may be an important source to Beach Lake, in addition to inputs from atmospheric deposition and historic mining waste.

- Nine (12%) of the reservoirs receive almost all their water from outside their watersheds, i.e., from water imports by regional, state and federal water conveyance projects. Mining waste and atmospheric deposition from global emissions are the primary anthropogenic sources to the supply reservoirs for these conveyance projects, which are Oroville, Don Pedro, and Tulloch Reservoirs.
    - For six of these nine reservoirs, atmospheric deposition from global emissions is the primary mercury source to their local watersheds.
    - For one of these, atmospheric deposition from a mix of local and global emissions is the primary mercury source to its local watershed.
    - For two of these reservoirs, local mining waste is the primary source.
- Finally, 28 (almost 40%) of the reservoirs on the 2010 303(d) List are in the Coast Ranges, which are naturally enriched in mercury. Water conveyance projects provide almost all the water to 3 of these reservoirs. Atmospheric deposition is the primary anthropogenic source to 18 of these reservoirs, i.e., there is little to no record of any mining activity in their watersheds. Mining waste contributes mercury to seven of these watersheds in the Coast Ranges.

The implications of these source assessment findings are reviewed in the next chapter.

7 ASSESSMENT OF ALLOCATION AND IMPLEMENTATION OPTIONS

Overview

Chapter Objectives

This chapter presents a review of potentially controllable factors and processes to reduce fish methylmercury concentrations, examples of possible control actions and management practices, as well as predictions for their effectiveness in mercury-impaired reservoirs in California. The objective of this chapter is to use these predictions along with key conclusions of the conceptual model, linkage, and source assessment chapters to develop TMDL allocations and implementation requirements that effectively reduce fish methylmercury concentrations and achieve the proposed sport fish, prey fish, and California least tern targets.

Foundation from Previous Chapters

The conceptual model, linkage analysis, and source assessment chapters identified mercury sources and presented many factors that influence mercury methylation and bioaccumulation in reservoirs. Key findings that provide a foundation for this chapter are:

- Inorganic mercury sources alone are not the primary driver of fish methylmercury levels (and reservoir mercury impairments). Multiple factors drive reservoir fish methylmercury levels:
  - Amount of mercury
  - Methylmercury production
  - Bioaccumulation
- Modern background soil mercury levels are elevated above natural background because mercury emissions and associated atmospheric deposition have increased greatly since the dawn of the industrial era. Modern background mercury levels vary greatly and are often higher than natural background levels—as much as two to ten times higher. It could take decades to centuries for industrial-era mercury in watershed soils to be depleted.
- Reducing sources of inorganic alone is not expected to enable attainment of the proposed sport fish mercury target in many reservoirs. The linkage analysis and source assessment results indicate that even if all anthropogenic mercury inputs were eliminated, there would still be impaired reservoirs. This demonstrates the need for an implementation plan that includes mercury methylation and bioaccumulation control actions in addition to source control.
- There are few opportunities for source control for some impaired reservoirs. Many impaired reservoirs have no known upstream mercury or gold mines, despite legacy mercury from historical mining activities being a widespread source. In addition, most impaired reservoirs have few or no upstream NPDES-permitted facility discharges, very

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Overview, continued

little urban area in their watersheds, and little atmospheric deposition attributed to anthropogenic emissions from California sources. Global industrial emissions may be the primary anthropogenic source to many mercury-impaired reservoirs.

Key Points from This Chapter

The large number of factors that control mercury methylation and bioaccumulation complicates resolving the mercury impairment in California reservoirs. However, the large number of factors also increases the number of possible tools that may be available to reduce reservoir methylmercury levels. There are a variety of mercury source control options and reservoir water chemistry and fisheries management practices that may be effective for reducing fish methylmercury concentrations.

Actions to reduce fish methylmercury levels likely will need to vary for each reservoir because of the many combinations of different mercury sources (e.g., some are natural or global and therefore not regulated by state and federal agencies), competing factors that control methylmercury production, and reservoir operational constraints. Reservoir-specific characteristics and operational requirements and mandates may not allow for all methylmercury management tools to be used in all reservoirs. Even so, the evaluation presented in this chapter indicates there may be a possible solution to reduce fish mercury levels in every reservoir.

Predictions for mercury source control include the following:

1. The lowest reservoir sediment mercury concentration that can be achieved in the foreseeable future (i.e., within the next several decades) is modern background soil mercury concentrations, versus natural (pre-industrial) background conditions.
2. Fish methylmercury levels at most reservoirs are expected to decline very slowly, if at all, if only local (California) source control actions are implemented.
    - Source control alone is expected to achieve measurable and relatively quick fish methylmercury reductions in only about 10% of the mercury-impaired reservoirs due to control of nearby mines and local atmospheric emissions.
    - Considering a longer timeframe, local source control alone is expected to achieve substantial fish methylmercury reductions in another 10% of the mercury-impaired reservoirs on the 2010 303(d) List.
    - Global industrial emissions are the primary anthropogenic source to more than 30% of 303(d)-listed reservoirs.
    - Climate change, predicted increases in global mercury emissions, and other regional processes may cause changes in reservoir water chemistry and fisheries that increase fish methylmercury levels.
3. Federal and state air emission regulations may already be sufficiently stringent to address atmospheric deposition from California anthropogenic sources. However, financing and enforcement of international air emissions controls will be needed to make necessary reductions from global sources.

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4. NPDES-permitted discharges are not a significant mercury source to 303(d)-listed reservoirs. In addition, facility mercury discharges are expected to decrease as a result of recent statewide rules and bans for mercury usage, and facility upgrades necessary to address other pollutants. Similarly, mercury discharges from municipal separate storm sewer system (MS4) are expected to decrease as a result of a variety of regulations.

Predictions for managing reservoir water chemistry and fisheries include the following and support the concept that additional pilot tests and associated studies of potential water chemistry and fisheries management practices are warranted:

1. In-reservoir methylmercury (water chemistry) management practices may be effective at reducing fish methylmercury concentrations in more than 80% of the 303(d)-listed reservoirs; these practices may be particularly effective in reservoirs that have strong anoxia; more than half of the 303(d)-listed reservoirs have strong anoxia.
2. Fisheries management practices such as nutrient management and intensive fishing may reduce fish methylmercury levels in more than two-thirds of the 303(d)-listed reservoirs.
3. Reservoir water chemistry and fisheries management practices have the potential to not only make measurable improvements in many reservoirs, but also, unlike many source control efforts, to do so relatively quickly (e.g., <10 years).

Implications

The evaluations and predictions in this chapter further highlight the need for the Reservoir Mercury Control Program to incorporate reservoir water chemistry and fisheries management practices in addition to mercury source control actions to achieve the proposed sport fish targets. In addition, this chapter identifies several key elements for an effective reservoir mercury control program, including but not limited to the following:

<u>Adaptive implementation</u>. The control program needs to incorporate an adaptive implementation approach that involves (a) taking immediate actions commensurate with available information, (b) defining and implementing a program for refining the information on which the immediate actions are based, and (c) modifying actions as necessary based on new information. The corresponding phases in implementing the Reservoir Mercury Control Program are referred to in this chapter as (a) first phase, (b) program review, and (c) later phases.

Water Board staff recommends taking immediate action based on currently available information for inorganic mercury source control, and conducting coordinated pilot tests and associated studies to assess in-reservoir water chemistry and fisheries management practices in representative reservoirs. Taking immediate source control actions based on currently available information allows California to make progress toward reducing reservoir fish methylmercury levels; simultaneously, we improve our understanding of mercury and methylmercury cycling through pilot tests and by observing how reservoirs respond to the immediate actions.

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Inorganic mercury allocations. The implementation plan needs to incorporate realistic expectations for source reductions and associated TMDL allocations for inorganic mercury sources.

Methylmercury allocations. A methylmercury allocation for methylmercury production within reservoirs is necessary, in addition to allocations for inorganic mercury sources, because inorganic mercury control alone is not expected to achieve the proposed sport fish target in every reservoir.

Reservoir-specific plans. As noted earlier, fish methylmercury reduction actions likely will need to vary for each reservoir because of the many combinations of different mercury sources, competing factors that control methylmercury production, and distinct operational constraints. Consequently, this control program will need to incorporate reservoir-specific, long-term management strategies developed by parties responsible for reservoir operations and fisheries management after coordinated pilot tests of representative reservoirs are completed.

Future changes. The allocation approach and implementation plan need to accommodate anticipated future changes, such as additional reservoirs determined to be mercury-impaired, population growth, new or expanded point source discharges, increases in global industrial emissions, climate change, and the creation of new reservoirs.

This chapter presents a review of potentially controllable factors and processes to reduce fish methylmercury concentrations, along with examples of possible control actions and management practices and predictions for their effectiveness in mercury-impaired reservoirs in California. These predictions, along with key conclusions of the conceptual model, linkage, and source assessment chapters, form the basis for staff recommendations for TMDL allocations and implementation requirements described in Chapters 8, 9, and 10.

This chapter has eight sections, as follows:

7.1 Approach to Assessing Potential Options

The conceptual model, linkage analysis, and source assessment chapters identified mercury sources and presented many factors that influence mercury methylation and bioaccumulation in reservoirs. This chapter evaluates a variety of potentially controllable factors and processes to reduce methylmercury concentrations in California reservoir fish. This evaluation lays the foundation for TMDL allocations and implementation requirements that are feasible to achieve the proposed sport fish target.

Inorganic mercury source reduction alone is not expected to enable attainment of the proposed sport fish target in many reservoirs. About 40% of the 74 reservoirs on the 2010 303(d) List for which TMDLs have not yet been adopted are impaired even though they have sediment total mercury concentrations that reflect typical modern and natural background levels. In addition, the linkage analysis predicted that several reservoirs would require sediment mercury concentrations lower than natural background to achieve the proposed target, which is not feasible. These findings indicate that even if all anthropogenic source inputs were eliminated, California would still have impaired reservoirs. Consequently, the first three sections of this chapter evaluate potential ways to manage within-reservoir methylmercury production and fish bioaccumulation, in addition to source reduction.

Because eliminating all anthropogenic sources is not a feasible goal, staff recommends allocations for mercury sources be established at economically and technically feasible levels. Consequently, this chapter provides evaluations of technically and economically feasible source reductions.

The next three sections (sections 7.2–7.4) focus on: (1) reduction of external (upstream) mercury sources; (2) management of within-reservoir processes that affect reservoir water methylmercury levels; and (3) management of fisheries to reduce bioaccumulation of methylmercury. Each of these sections contains the following:

- Review of potentially controllable processes;
- Predictions for how effective controlling these factors may be for reducing fish methylmercury levels in California reservoirs and some limitations on their applicability;
- Initial projections for where particular types of source control and reservoir and fisheries management activities could be effective at reducing reservoir fish methylmercury levels and ultimately achieve Reservoir Mercury Control Program goals; and
- Recommendations for allocations and implementation plan requirements.

Staff does not expect all processes identified in sections 7.2 – 7.4 will be controllable for all mercury-impaired reservoirs. Fish methylmercury reduction actions will no doubt vary for each reservoir because of the many different combinations of mercury sources, reservoir characteristics, and distinct operational constraints. Table 7.1 provides an initial identification of which of the 74 reservoirs on the 2010 303(d) List for which TMDLs have not yet been adopted may be amenable to each of the different types of source control and reservoir water and fisheries management activities. In addition, section 7.5 describes competing factors that control methylmercury production and influence selection of methylmercury management tools, and identifies the need for reservoir-specific management strategies. Section 7.6 outlines considerations and potential mercury management tools for new reservoirs and identifies the need for operations plans for new reservoirs to include management activities to prevent or reduce methylmercury production and ongoing monitoring to assess the effectiveness of the control actions.

Finally, sections 7.7 and 7.8 outline the consequences of no action as well as potential consequences of implementing the recommended approach. There are a variety of ongoing regional and global processes that may ultimately lead to additional reservoir impairments—as well as worsen existing impairments—if nothing is done to reduce fish methylmercury levels.

Definition of TMDL and TMDL Allocations

A TMDL is the total amount of a pollutant that a water body can assimilate and still attain beneficial uses. A TMDL is "[t]he sum of the individual [*waste load allocations*] for point sources and [*load allocations*] for nonpoint sources and natural background" (Code of Federal Regulations, title 40, § 130.2[i]). Allocations describe mercury reductions needed by source category. Waste load allocations (WLAs) apply to discharges from existing and future NPDES-permitted facilities, while load allocations (LAs) apply to mining waste, natural background soils, atmospheric deposition, and in-reservoir methylmercury production.

A TMDL need not be stated as a daily load (Code of Federal Regulations, title 40, § 130.2[i]). Other measures besides a daily load are allowed if appropriate. For example, allocations can be expressed in terms of concentration rather than load, and for seasonal or annual periods. TMDLs require numeric targets, therefore, the proposed targets for reservoirs are the Water Quality Objectives (see Chapter 2).

Definition of Adaptive Implementation

Many of staff's recommendations involve taking an adaptive approach to implementing the Reservoir Mercury Control Program. Adaptive management is a systematic process that uses scientific information to help formulate management policies and practices. Additionally, adaptive management allows for continually improving those policies and practices by learning from the outcomes of research, pilot tests and associated studies, implementation, and monitoring programs.

Adaptive implementation entails applying the scientific method to the TMDL. A National Research Council review of U.S. EPA's TMDL program strongly suggests that the key to improving the application of science in the TMDL program is to apply the scientific method to TMDL implementation (NRC 2001). For a TMDL, applying the scientific method involves taking immediate actions commensurate with available information, defining and implementing a program for refining the information on which the immediate actions are based, and modifying actions as necessary based on new information. This approach allows the impaired waters to make progress toward attaining water quality standards while regulators and stakeholders improve their understanding of the system through research and by observing how it responds to the immediate actions.

As described in the following sections, staff recommends taking immediate action based on currently available information for inorganic mercury source control, and conducting pilot tests to assess in-reservoir water chemistry and fisheries management practices. Taking immediate source control actions based on currently available information allows California to make progress toward reducing reservoir fish methylmercury levels; simultaneously, understanding of mercury and methylmercury cycling is improved through pilot tests and by observing how reservoirs respond to the immediate actions.

7.2 Mercury Source Reduction

As reviewed in Chapters 4 and 5, methylmercury production is a function of total mercury content of sediment. The linkage analysis then determined that reservoir sediment mercury concentrations have the second strongest correlation with reservoir fish methylmercury concentrations of any single factor evaluated for California reservoirs. Reservoir sediment mercury concentrations are associated with inorganic mercury sources such as watershed soils, upstream mercury and gold mine sites, discharges from urban and industrial activities, and atmospheric deposition.

This section reviews potential mercury source reductions by individual source type. The primary anthropogenic mercury sources to impaired reservoirs include historical mercury and gold mining activities, atmospheric deposition, and discharges from urban and industrial activities.

Notably, mercury source controls have reduced fish methylmercury concentrations around the world. For example, Figure 7.1 shows a comparison of fish methylmercury concentrations before and after total mercury controls from 11 industrial sites. When mercury from industrial discharges (i.e. not air emissions) was reduced or eliminated, reductions in fish methylmercury levels were observed (see section 7.2.2 regarding reductions in fish methylmercury concentrations resulting from decreases in emissions). At some contaminated sites, additional mitigation measures were taken, such as excavating contaminated sediment from a floodplain, treating groundwater prior to discharge to surface water, and dredging contaminated river sediment. Sites with additional actions typically had greater reductions in fish methylmercury levels.

However, as discussed in section 7.2.7, the new equilibrium fish methylmercury value after removing a mercury source is usually higher than in adjoining uncontaminated waterways and is often greater than what is recommended as safe for human consumption. Consequently, this section provides initial projections for where particular types of inorganic mercury source control could be effective at reducing reservoir fish methylmercury levels and where additional actions will be needed to achieve the proposed sport fish target. Finally, because of the potential importance of watershed methylmercury sources on water methylmercury levels in some reservoirs, the last part of this section reviews potentially controllable processes that can lead to watershed methylmercury source reduction.

7.2.1 Mine Sites and Mining Waste in Downstream Creeks

Mines (not atmospheric deposition) are the source of California’s highest fish methylmercury concentrations, as illustrated by comparing graphs A and B in Figure 7.2. Consequently, the Regional Water Boards have already completed mercury TMDLs for many of the worst problems, e.g., Clear Lake and Guadalupe River watershed. However, mines are upstream of only 48 of the 74 303(d)-listed reservoirs. Even where there are mines upstream, the reservoirs may not have elevated sediment mercury. This section accounts for these factors and proposes allocations and implementation actions for mercury discharged from mines.

Potentially controllable processes

Erosion of mining waste from historical mining activities (mercury mines and gold and other mines where mercury was used) can discharge highly mercury-contaminated wastes to reservoirs. Historical mining activities took place in watersheds of many mercury-impaired reservoirs in California.

Mine site remediation and erosion control can greatly reduce discharges of mercury contaminated sediment (Kirchner et al. 2011). Examples of mine site remediation are proper burial of mining waste (characterize, excavate, stockpile, haul, and consolidate mining waste in engineered, onsite landfills); and removal and proper disposal or cleaning of mercury-contaminated equipment. Examples of mining-related erosion control are surface water diversion channels and subdrains that route clean surface water runoff away from mining waste; re-contouring and terracing of steep or exposed slopes to reduce and control surface erosion and eliminate potential for mass wasting and slope failure; and planting exposed soils with native vegetation to minimize sheet-flow erosion of mining waste and contaminated soils. Remediation at the Gambonini mercury mine site (north of San Francisco) reduced discharges of mercury by more than 90% by re-contouring the primary mine waste deposit, installing a surface water runoff drainage system, and planting exposed soils with native vegetation (Kirchner et al. 2011).

At many sites, mining waste has moved offsite and is deposited along tens or hundreds of miles of downstream streams and rivers. Similar to mines, erosion from these downstream depositional areas can contribute mercury-contaminated sediments to reservoirs. Depositional areas can include floodplains, beds and banks of creek channels, and in-stream depositional features such as point bars and backwater channels. Similar to mine sites, bank stabilization (erosion control) or removal of contaminated sediment followed by creek restoration can reduce mercury and sediment discharges.

After upstream mine-related remediation and erosion control projects are completed, natural soil erosion will provide new, non-mine impacted sediment to the reservoir. These new sediments will have lower (background) mercury concentrations and will dilute and bury the mining waste as they settle on the reservoir bottom. Such gradual burial can be effective at reducing mercury concentrations in the active methylation zone of a reservoir. Burial, however, is not a quick process. The length of time for burial is dependent on the erosion rate and relative size of the watershed compared to the reservoir. More erosive geology, more frequent and larger storm events, and relatively large watersheds all speed burial.

Predictions for improvements

In this section, staff provides predictions for mine site and downstream mining waste remediation and stabilization to reduce fish methylmercury concentrations. These predictions form the basis of the proposed TMDL load allocations for runoff from mine sites and mining wastes. In addition, the predictions highlight where mining waste cleanup will likely reduce mercury loading to reservoirs and decrease reservoir fish methylmercury levels.

Lowest feasible soil and sediment mercury levels and basis for allocations

Millions of kilograms of mercury entered California's waterways from mercury and gold mining operations in the 1800's and early 1900's, and much of this occurred upstream of reservoirs. Inorganic mercury from mine sites is predominately attached to fine-grained soils and is transported via natural and anthropogenic erosional processes.

As noted in Chapter 6, elevated modern background soil mercury levels need to be considered when developing allocations for particle-bound mercury sources such as watershed soils and mine sites. In general, it is not reasonable to expect remediation actions to reduce runoff from mine sites and downstream mining waste to levels lower than modern background.

The Chapter 6 source assessment determined that modern background mercury levels in soils and sediments vary greatly and are typically much higher than natural background levels—as much as two to ten times higher. It could take decades to centuries for industrial-era mercury in watershed soils to be depleted. The source assessment determined that the following values characterize region-specific, particle-bound mercury sources to reservoirs and take into account the variability in modern background levels in California's different mercury regions:

- Trace mercury areas: 0.1 mg/kg
- Mercury-enriched region: 0.3 mg/kg
- Mineralized zones: 400 mg/kg

Consequently, staff recommends TMDL load allocations for historical mining sites and downstream mining waste be set equal to these values. The allocations would apply to runoff from mine sites and mining waste; that is, the allocations would be for total mercury concentration in suspended sediment, i.e., particulate mercury. This is appropriate because mercury from mine sites is predominately attached to fine-grained soils and transported via erosional processes and runoff to surface waters.

Mercury concentrations on suspended sediment are best characterized by the annual median. It is possible to translate these allocations to measurements of mercury in surface soil using the following concepts. Fines are the silt and clay portion of soil that is less than 63 microns in diameter and is readily suspended in the water column. Hence, measurements of mercury in erodible surface soil fines yield comparable measurements to suspended sediment. Measurements of mercury in erodible soil fines can be collected at one time whereas measurements of mercury in suspended sediments are evaluated for multiple water sampling events over a year of runoff, particularly during episodic storm and high flow events.

There is precedent for setting concentration-based allocations for erodible mining waste. The adopted Guadalupe River Watershed and Walker Creek Watershed mercury TMDLs assigned concentration-based mercury allocations to erodible mining waste discharged from mine sites and depositional areas in creeks that drain mines (SFBRWQCB 2008a and 2008b).

Effectiveness of erosion control and stabilization to reduce mining waste contributions

Based on improvements at the Gambonini Mine site (Kirchner et al. 2011), staff expects greater than 90% mercury load reduction to result from erosion control, and about 95% reduction if mining waste is capped. Staff expects such practices would reduce the load contributions to reservoirs from mine sites and offsite mining waste to levels comparable to background. However, in some cases the suspended sediment mercury concentrations in runoff from mine sites and offsite mining waste may still be elevated compared to modern background levels and proposed allocations. Consequently, staff recommends TMDL load allocations for mine sites and mining waste be implemented as management practices and not used as cleanup standards. Chapter 9 provides more information about how TMDL load allocations can be implemented as management practices. Cleanup standards may be established by other programs and are typically based on a risk evaluation that identifies the most sensitive receptor, whether on-site or downstream.

There is precedent for this implementation approach. The Guadalupe River Watershed and Walker Creek Watershed mercury TMDL allocations for mine sites and downstream mining waste are implemented as management measures to prevent excessive erosion or re-suspension of mercury-laden sediment from mine sites and downstream depositional areas (SFBRWQCB 2008a and 2008b). Excessive erosion was defined as resulting from anthropogenic alterations to the land surface that produce, for example, landslides, slumps, gullies, rills, and loss of vegetation. The goal of the Guadalupe and Walker TMDL allocations' implementation is to restore the landscape by reasonable and feasible means to nearly natural erosion rates. The allocation and implementation approach of the Guadalupe and Walker TMDLs was designed to build upon existing efforts that have successfully reduced mercury loads in these watersheds (SFBRWQCB 2008a and 2008b).

Effectiveness of controlling mining waste to reduce reservoir sediment mercury and fish methylmercury levels

Staff evaluated the potential effectiveness of controlling mining waste on reducing sediment mercury and fish methylmercury levels in reservoirs using the following three methods, with each further described below:

(1) Comparison of reservoir sediment mercury concentrations and watershed mining density;

(2) Comparison of fish methylmercury levels in reservoirs with and without upstream mines; and

(3) Comparison of neighboring reservoirs, one with and one without upstream mine sites.

<u>(1) Comparison of reservoir sediment mercury concentrations and watershed mining density</u>. Fifty-three of 74 303(d)-listed reservoirs are downstream of mines or adjacent to dredge tailings. Mines are associated with elevated reservoir sediment mercury levels. Reservoir surface sediment mercury data are available for 46 of the 74 reservoirs. Fourteen of 17 reservoirs with average sediment mercury concentrations elevated above modern background levels have watersheds with moderate to high mercury and gold mine site densities (Table H.1 in Appendix H). Of these 14 reservoirs, 10 have high mine site densities and highly elevated sediment mercury concentrations (i.e., more than twice modern background levels): Lake Berryessa, Camp Far West Reservoir, Lake Combie, Davis Creek Reservoir, Englebright Lake, Marsh Creek Reservoir, Lake Nacimiento, New Melones Reservoir, Rollins Reservoir, and Lake Wildwood. Fish methylmercury concentrations in these 10 reservoirs are elevated and range from two to ten times the proposed sport fish target. Remediation of mine sites and mining waste in stream channels may be particularly effective at reducing fish methylmercury concentrations in these ten reservoirs.

However, even if a reservoir has mine sites upstream of it, the reservoir sediment may not be elevated above background levels. For example, 30 of the 46 reservoirs with sediment mercury data have elevated watershed mine site densities (Table H.1); of these 30, 17 have sediment mercury concentrations within modern background levels, and 8 of these 17 reservoirs have sediment mercury concentrations within natural background levels. Consequently, mine remediation may not result in substantial fish methylmercury reductions in these 17 reservoirs.

As discussed in section 6.3.3, the inconsistent association between mine site density and reservoir sediment mercury and fish methylmercury concentrations could be the result of several possible factors. Additional sediment mercury monitoring may be needed to more accurately determine how much mining waste contaminates reservoir sediments.

(2) Comparison of fish methylmercury levels in reservoirs with and without upstream mines. Figure 7.2 compares reservoirs with and without upstream mine sites (graphs A and B, respectively). Figure 7.2 further compares reservoir fish methylmercury concentrations to REMSAD modeled 2001 atmospheric mercury deposition rates. These graphs include 303(d)-listed reservoirs as well as other reservoirs and lakes. These graphs illustrate how there is no one source or factor that explains the mercury impairment in every reservoir. Graph (A) shows how reservoirs with the very highest fish methylmercury levels have upstream historical mine sites. However, graph (A) also shows that presence of upstream mine sites is frequently not associated with elevated fish methylmercury levels in downstream reservoirs. Further, graph (B) shows how there are numerous reservoirs with elevated fish methylmercury levels but no upstream mine sites. There are 60 reservoirs with high reservoir fish methylmercury levels but low atmospheric deposition rates and no upstream mines sites, an indication that factors other than mercury sources are important.

(3) Comparison of neighboring reservoirs. We can further compare neighboring reservoirs, one with and one without upstream mine sites.

(a) Lake San Antonio compared to Lake Nacimiento. The Lake San Antonio watershed forms the northern border of the Lake Nacimiento watershed in the Coast Ranges. Both are on the 2010 303(d) List as mercury impaired and are included in the Chapter 6 source assessment. High trophic level fish in Lake Nacimiento have four times as much methylmercury as fish in Lake San Antonio (i.e., 1.1 vs. 0.27 mg/kg; Table 1.3 in Chapter 1) and higher geomean and average sediment mercury concentrations (Table 6.4 in Chapter 6).

Mines are the main difference in sources to these reservoirs. San Antonio has no record of historical mercury or silver mining and only one gold prospect. In contrast, Lake Nacimiento has numerous historical mercury mine sites, including the Klau/Buena Vista Mines in the Las Tablas

Creek subwatershed, which are a major source of mercury to Lake Nacimiento and are USEPA Superfund sites (CCRWQCB 2002; CH2M Hill 2008.). The REMSAD-modeled atmospheric deposition rates for both reservoirs and their watersheds are low, with most deposition resulting from natural and global industrial emissions (versus industrial emissions in California) (Table 6.11).

Remediation of the Klau/Buena Vista Mines and associated downstream mining waste is expected to improve fish methylmercury levels in Lake Nacimiento. However, the remediation may not result in the proposed sport fish target being achieved in Lake Nacimiento for several reasons.

First, fish methylmercury concentrations in the comparison lake, Lake San Antonio, exceed the proposed target. Even though Lake San Antonio average sediment mercury concentrations (0.07 mg/kg) are already comparable to natural background levels in the Coast Ranges enriched region, its fish methylmercury concentrations exceed the proposed target. Average methylmercury concentration in high trophic level fish is 0.27 mg/kg (see Table 1.3 in Chapter 1). This indicates that actions other than source control likely will be needed to achieve the proposed sport fish target in both Lake Nacimiento and Lake San Antonio.

Second, there are distinct differences in geology that affect soil mercury concentrations. The Lake Nacimiento watershed has older marine sedimentary formations with Franciscan complex as well as ultramafic formations, while the Lake San Antonio watershed has younger marine sedimentary formations and some nonmarine formations (CDOC-DMG 2000). Consequently, Lake Nacimiento is expected to have higher natural background sediment mercury concentrations than Lake San Antonio. This is also indicated by watershed soil mercury data. The maximum soil mercury concentration in the San Antonio watershed is 0.14 mg/kg. In contrast, the maximum soil mercury concentration in the Nacimiento watershed in "background" areas is 1.4 mg/kg (USGS 2008; CCRWQCB 2002).

Finally, even if the two reservoirs had the same background mercury levels, there are other factors that were identified in the conceptual model and linkage analysis—water level fluctuations, aqueous methylmercury concentration, and ratio of methylmercury-to-chlorophyll—as important for methylmercury production and bioaccumulation (see Chapters 4 and 5). Lake Nacimiento has twice as much water level fluctuation on average compared to Lake San Antonio, twice the average methylmercury in water, four times the peak methylmercury, and only a third of the chlorophyll (see Table 5.2). In addition, Nacimiento's methylmercury-to-chlorophyll ratio is more than five times higher than San Antonio's. These factors help to explain why fish in Lake Nacimiento have higher methylmercury levels than fish in San Antonio, and may continue to have higher methylmercury levels even after mining waste is remediated if no other management actions take place to control methylmercury production and bioaccumulation in the food web.

(b) Almaden, Guadalupe, and Lexington Reservoirs. Similarly, we can compare Guadalupe and Almaden Reservoirs, located adjacent to New Almaden mercury mining district in the Guadalupe River Watershed, to Lexington Reservoir in the same watershed but not downstream of mercury mines. (Note that Guadalupe and Almaden Reservoirs are addressed by the already-adopted Guadalupe River Watershed mercury TMDL and are excluded from this

Reservoir Mercury Control Program; see Chapter 1.) Methylmercury in 350 mm largemouth bass are 4.2 and 3.1 mg/kg in Guadalupe and Almaden Reservoirs, and 0.44 mg/kg in Lexington Reservoir, which is about twice the proposed sport fish target of 0.2 mg/kg. Remediation of New Almaden would improve fish methylmercury levels possibly comparable to Lexington Reservoir, but not achieve the sport fish target proposed for this statewide program. (Lexington Reservoir is an example of a reservoir to be included in statewide this program; see "next set of impaired reservoirs" in section 1.6.3.)

Conclusions. All three of the above comparisons indicate historical mine sites may be an important contributor to many reservoir impairments. However, some reservoirs may not be mercury impaired even if there are historical mine sites in their watersheds. Further, remediating mine sites and downstream mining waste in some watersheds may not achieve the proposed sport fish target and, in some reservoirs, may not substantially reduce reservoir sediment mercury levels. These observations support the linkage analysis findings that methylation and bioaccumulation are important factors in addition to the amount of mercury. In addition, these observations indicate the need for a prioritization strategy for mine site and downstream mining waste remediation efforts.

Nonetheless, active erosion and discharges of mining waste pollute downstream waters, including many mercury-impaired reservoirs. Therefore, staff recommends the implementation plan include an assessment and prioritization of mine sites and their downstream areas.

Prioritization of mine sites and downstream mining waste

Staff recommends historical mine sites and downstream mining waste be prioritized based on the likelihood of their remediation resulting in reductions in reservoir sediment mercury concentrations, and the timeframe to achieve these reductions. As reviewed in Chapter 6 (particularly Figure 6.9), the extent of reservoir pollution from mining waste is based on several factors, including but not limited to the following:

- The type and productivity of mine sites and processing methods used. For example, mercury losses were greater with placer mining than lode mining, and loss rates for both decreased with time as new mining methods were developed (Churchill 2000).
- The number of mine sites compared to the size of the watershed (i.e., watershed mine density). Watersheds with a low mine density, and large watersheds in general, are more likely to have many sources of sediment not contaminated by mining to mix with or bury inputs from mine sites.
- Mine site distance from the reservoir. Contaminated material eroded from mine sites far upstream of reservoirs may be removed from the aquatic system by irrigation diversions and deposition behind dams and in floodplains before the material is transported to downstream reservoirs. In contrast, contaminated material eroded from mine sites located adjacent to or immediately upstream of reservoirs is very likely to be delivered to reservoirs.

Remediation of mining waste is expected to result in measurable reductions in reservoir sediment mercury concentrations where:

- Reservoir sediment mercury concentrations exceed modern background levels. This is an indication that the watersheds do not provide enough background sediment to mix with or bury inputs from historical mines, regardless of watershed size, or productivity of and treatment processes employed by the mines; and
- There is on-going discharge and/or erosion of mercury-contaminated material from the sites. Because these mines are legacies from long ago, there may not be on-going discharge and/or erosion of mercury-contaminated material from many mine sites or their downstream creeks, and so contributions from these mines may no longer appreciably affect downstream reservoirs. Consequently, it is appropriate to focus effort where there is active discharge and/or erosion of mercury-contaminated mining waste at mine sites and in downstream areas.

Further, remediation of mining waste is expected to result in both measurable and relatively quick reductions (e.g., within about 10 years) in reservoir sediment and fish methylmercury concentrations where:

- All actively discharging or eroding mine sites in the reservoir watershed are localized to a relatively small area of the watershed. Highly contaminated soils are not likely to be dispersed throughout a reservoir's watershed if mine sites are relatively localized, e.g., within one tributary subwatershed.
- All actively eroding mine sites in the reservoir watershed are located very close to a reservoir. If mine sites discharge directly to a reservoir or to tributary streams not far upstream (e.g., 10 km upstream of the reservoir), then there will not be tens or hundreds of miles of creek channels with highly contaminated sediment that can be difficult or impossible to remediate.

Consequently, measurable and relatively quick reservoir improvements are expected from the remediation of the highest priority mine sites based on the two above bulleted points. Priority could decrease with distance upstream and fewer signs of erosion. Section 7.2.7 and Table 7.1 provide examples of reservoirs where mining waste remediation may result in measurable and timely fish methylmercury reductions. Chapter 9 provides specific recommendations for a prioritization strategy.

Recommendations

Based on considerations and evaluations outlined in previous sections, staff recommends the following approach for TMDL load allocations for erodible material discharged from mine sites and downstream mining waste in creeks and rivers in the watersheds of mercury-impaired reservoirs, by geographic region:

- Mercury-enriched region: 0.3 mg/kg (dry weight, annual median)
- Mercury mineralized zones: 400 mg/kg (dry weight, annual median)
- Trace mercury areas: 0.1 mg/kg (dry weight, annual median)

These allocations are for total mercury concentration in suspended sediment, i.e., particulate mercury, in discharges. We recommend the allocations be implemented as management practices and not used as cleanup standards. Cleanup standards will be established by other programs, and are typically based on a risk evaluation that identifies the most sensitive receptor, whether on-site or downstream.

In addition, staff recommends the implementation plan contain a prioritization strategy for remediating historical mine sites and downstream mining waste based on the likelihood of their remediation resulting in measurable and timely reductions in downstream reservoir sediment mercury and fish methylmercury concentrations.

7.2.2 Atmospheric Deposition

As discussed in Chapter 6, rates of atmospheric deposition vary across California, and atmospheric deposition is the primary anthropogenic mercury source to many impaired reservoirs. In addition, mercury from atmospheric deposition falling directly onto reservoir surfaces is likely more bioavailable than mercury from other sources such as cinnabar from mercury mine waste. However, rates of atmospheric deposition do not correlate directly with fish methylmercury concentrations, as illustrated on Figure 7.2 (graph B). Further, mines, not atmospheric deposition, are the source of California's highest fish methylmercury concentrations, as illustrated by comparing graphs A and B in Figure 7.2. This is no surprise, because the conceptual model and linkage analysis in Chapters 4 and 5 explained that methylation and bioaccumulation are also important factors. This section accounts for this complexity and proposes allocations and implementation actions for mercury from atmospheric deposition.

Potentially controllable processes

Mercury is emitted to the atmosphere from natural sources, particularly volcanoes, and from industrial processes, notably burning coal. These emissions eventually settle out of the atmosphere and deposit on water and landscape surfaces; hence this source is called atmospheric deposition. Natural atmospheric deposition is not controllable. In this section the focus is on control of atmospheric deposition from industrial emissions.

Reductions in mercury emissions and consequent reductions in atmospheric deposition directly to the water surface have been shown to result in reductions in reservoir water and biota mercury levels. For example, in Wisconsin a 30% reduction in mercury atmospheric deposition resulted in a 13% and 27% reduction in aqueous total mercury concentrations in Devils Lake and Little Rock Lake, respectively (Watras 2009). The authors hypothesized that differences in reductions were likely due to varied influences in their terrestrial watersheds.

In other regions of the United States, reductions in atmospheric mercury emissions and deposition also had concomitant reductions in reservoir biota methylmercury concentrations. For example, in Massachusetts, the adoption and implementation of a comprehensive state and regional mercury emission reduction plan resulted in the decrease of mercury emissions by 87% due to pollution controls on municipal solid waste combustors and the closure of medical waste incinerators (Hutcheson et al. 2006). Within 36 to 48 months after reduction of local emissions, statistically significant reductions in methylmercury concentrations were observed in yellow perch (20–62% reductions) and largemouth bass (16–55% reductions) from 17 lakes.

In New Hampshire, new restrictions on incinerators resulted in 45% reductions in emissions, and during the same period, loon methylmercury concentrations decreased by 36% at downwind lakes (Evers et al. 2007). And finally, in a Florida Everglades mercury TMDL study, 99% reductions in incinerator mercury emissions since the 1980's resulted in approximately 60% reductions in fish and wildlife methylmercury concentrations since the 1990's (Atkeson et al. 2003).

These studies demonstrated relatively fast (less than 10 years) and significant reductions (15–60%) in biotic methylmercury levels after atmospheric mercury reductions, where atmospheric deposition was the dominant source in the water bodies.

Predictions for improvements

This section provides predictions for reductions in atmospheric deposition and expectations for resulting reductions in fish methylmercury concentrations. These predictions, combined with findings described in the linkage analysis and source assessment chapters, form a basis for TMDL load allocations for atmospheric deposition in California.

Factors to consider

The following paragraphs highlight several factors to consider when assessing potential reductions in atmospheric deposition and fish methylmercury in California's reservoirs.

<u>Atmospheric deposition is an important factor, but not the most important factor, driving mercury impairments at most California reservoirs</u>. Most California reservoirs receive mercury from a variety of sources. Consequently, fish methylmercury levels in many reservoirs may not decrease much in response to emissions reductions. Further, the linkage analysis (Chapter 5) found that atmospheric deposition was a statistically significant but minor factor explaining fish methylmercury concentrations in California reservoirs (see Table B.7 in Appendix B).

Figure 7.2 (B) illustrates this finding, where the highest atmospheric deposition rates do not correspond to the highest fish methylmercury concentrations in California reservoirs. Figure 7.2 indicates there is no single factor that explains mercury impairment in every reservoir, because not all reservoirs with mines upstream or high rates of atmospheric deposition have high levels of methylmercury in fish. These observations support the linkage analysis findings that methylation and bioaccumulation are also important factors in addition to source inputs, and that multiple actions will be required to achieve the proposed sport fish target.

<u>Anthropogenic emissions from California sources account for only a small portion of atmospheric deposition in California</u>. Anthropogenic sources within California contributed only about 10% of all mercury deposition in California in 2001, according to USEPA's REMSAD atmospheric deposition model. (2001 is the baseline year for the atmospheric deposition source analysis described in Chapter 6.) The REMSAD model attributed the majority (about 90%) of this deposition to natural and global anthropogenic emissions.

<u>Anthropogenic emissions from California sources may be important to some reservoirs</u>. Although California anthropogenic emissions do not account for much of the overall mercury deposition in California overall, it still may be an important source to some reservoirs for the following reasons:

- California anthropogenic emissions may contribute substantially—50% to >80% per the REMSAD 2001 model run—to deposition in some areas of California. Reducing emissions from 2001 levels is expected to result in measurable reductions in atmospheric deposition and fish methylmercury levels in several 303(d)-listed reservoirs. The REMSAD model attributes more than 50% of atmospheric deposition to California anthropogenic emissions at 4 303(d)-listed reservoirs in 2001: El Dorado Lakes, Indian Valley Reservoir, Lake Herman, and Puddingstone Reservoir. Emissions from municipal waste incineration, geothermal power production, petroleum refineries, and cement plants are likely the most important anthropogenic contributors to these reservoirs. Emissions from several of these sources have decreased by 60% to 70% since 2001. (See Chapter 10 Monitoring Plan regarding fish sampling in the reservoirs where reductions are expected in order to answer atmospheric deposition monitoring question 1b.)
- Reducing California emissions is expected to reduce fish methylmercury levels in reservoirs not yet on the 303(d) List, particularly reservoirs near major population centers and industrial areas such as the Los Angeles region. This assumes that increases in global anthropogenic sources do not offset reductions from California sources.

Global industrial emissions are an important source to California reservoirs. Reducing global emissions is particularly important for reservoirs where there are no other known local anthropogenic sources. Global anthropogenic emissions are the primary anthropogenic source to 17 of the 74 (23%) 303(d)-listed reservoirs (see Table 6.12). USEPA's REMSAD 2001 model run and global source inventories indicate about 60% of all atmospheric deposition in California comes from anthropogenic emissions outside of California. Anthropogenic emission increases from global sources are expected to worsen existing reservoir impairments and create new impairments.

Authority to regulate local and global industrial emissions. Air pollution and associated air emissions are not subject to the direct authority of the State Water Board or Regional Water Boards. The responsibility for controlling air pollution from California emissions is shared between 35 local air districts, the California Air Resources Board (ARB), and the USEPA.

While the local air districts, ARB, and USEPA have authority to control emissions from sources in California, they do not have authority in other countries. Consequently, implementation of global treaties will be required to make substantial reductions in atmospheric deposition at many California reservoirs.

Conclusions: Allocations for atmospheric deposition need to incorporate feasible reductions. Allocations for atmospheric deposition cannot be considered feasible if they entail local or global emission reductions that are substantially more stringent than considered economically or technically possible. Staff recommends allocations and implementation actions for atmospheric deposition be based on recent forecasts and reduction scenarios that take into account California emission reductions since 2001 (the REMSAD model baseline year). Allocations and implementation should also take into account recently adopted standards, economic and population growth, known emission control technologies, and expected technology improvements and implementation.

Recent and anticipated changes in anthropogenic emissions

As described in more detail in Chapter 6 and Appendix D, anthropogenic emissions from California and other United States and European sources have decreased substantially since 2001:

- Total reported emissions from California anthropogenic sources decreased by more than 50% between 2001 and 2008.
- Likewise, United States emissions decreased by almost 60% between 1990 and 2005, and by about another 40% between 2005 and 2008.
- Similarly, emissions from Europe decreased by more than 60% between 1990 and 2005.

While anthropogenic emissions from several continents have decreased in recent years, mercury emissions from elsewhere, especially Asia, have increased. Emissions from Asia increased by more than 50% between 1990 and 1995, with less significant increases between 1995 and 2005. Emissions from Asia account for about 40% (in 1990) to nearly 70% (in 2005) of all global emissions.

Future changes in mercury emissions are dependent on several variables, including national and regional economies, development and implementation of emission control technologies, further regulatory changes, and global climate change (AMAP/UNEP 2008). To learn about potential future trends in local and global anthropogenic mercury emissions, staff reviewed the following:

- USEPA mercury emission standards and associated predictions for emission reductions;
- California-specific emission reduction programs and associated predictions; and
- Reduction scenarios for global anthropogenic emissions.

Section H.1 in Appendix H describes each of these in detail. These reviews indicate that, compared to the 2001 baseline, it is feasible to reduce anthropogenic emission sources in California by about two-thirds, and out-of-state anthropogenic emissions by half. Staff proposes corresponding allocations as described in the next section.

Basis for allocations

Staff recommends using the statewide load allocation approach for atmospheric deposition approved by USEPA for the Northeast States Regional Mercury TMDL and Minnesota Statewide Mercury TMDL (CDEP 2007; MPCA 2007). These TMDLs developed three separate statewide allocations for atmospheric deposition attributed to emissions from (1) in-state anthropogenic sources, (2) out-of-state (global) anthropogenic sources, and (3) natural sources.

(1) Deposition attributed to in-state anthropogenic emissions. Staff recommends the statewide load allocation for atmospheric deposition attributed to California anthropogenic sources incorporate a 66% reduction from the 2001 baseline deposition load

(680 kg/yr * (1 - 0.66) = 230 kg/yr; Table 7.2). This reduction includes emission reductions observed between 2001 and 2008 plus feasible emission reductions predicted for the future, and takes into account population growth and other factors (see section H.2 in Appendix H).

(2) Deposition attributed to out-of-state anthropogenic emissions. Staff recommends the statewide load allocation for atmospheric deposition attributed to anthropogenic sources outside of California incorporate a 50% reduction from to the 2001 baseline deposition load (3,200 kg/yr * 0.5 = 1,600 kg/yr; Table 7.2). This reduction includes predicted emission reductions based on the emission scenario inventories developed by the UNEP/AMAP study described in Appendix H and takes into account population growth and other factors (see section H.1 in Appendix H).

(3) Deposition attributed to natural emissions. Staff recommends the statewide load allocation for atmospheric deposition from natural sources be set equal to the existing load, as was done for the Northeast States Regional Mercury TMDL and Minnesota Statewide Mercury TMDL. As reviewed in Chapter 6, the USEPA's REMSAD 2001 model output and literature indicate natural sources contributed about 26% of all mercury deposition in California (about 1,400 kg/yr, Table 7.2). Natural mercury sources include volcanoes, geologic deposits, and volatilization from the ocean and cannot be controlled.

Implications. Achieving proposed load allocations for atmospheric deposition would reduce the total statewide atmospheric mercury deposition load by about 40% from 2001 baseline year (Table 7.2). Atmospheric deposition rates associated with different California and global sources vary across the state. Statewide deposition rates and the associated percent reductions that would result if allocations were achieved can be predicted using the REMSAD model 2001 output and the predicted reductions for different sources (Figure 7.3). Where California anthropogenic emissions were highest in 2001, reductions of up to 90% are expected.

At this time, new emission control programs may not be warranted since substantial emission reductions have occurred since 2001 in California and additional substantial reductions are expected under recently adopted emission standards and programs. Recent Air Resources Board and USEPA programs developed to reduce mercury greenhouse gas emissions should be fully implemented by 2020. As a measure of effectiveness, USEPA and Air Resources Board should evaluate changes in statewide emissions to assess progress towards meeting the load allocation. In addition, USEPA should update the REMSAD model to incorporate updated emission inventories, including nonpoint sources, which are likely important in some areas of California.

In addition, USEPA and Air Resources Board could evaluate changes in regional emissions that contribute to California emissions hotspots. The USEPA REMSAD 2001 model run identified 18 hotspots in California where California anthropogenic emissions may account for 20% or more of all 2001 deposition (section 6.4.4). Emissions in all but three of the hotspots substantially decreased since 2001. The Air Resources Board and USEPA could use future emission inventories and the REMSAD model (or a higher resolution model) to assess regional emissions and associated deposition in these three and other hotspot areas. If emissions that contribute to making the hotspots do not decrease, then the Water Boards and Air Resources

Board should consider the development of regional load allocations for atmospheric deposition in later phases of this program.

Recommendations

Based on considerations and evaluations outlined in previous sections, staff recommends the following for TMDL load allocations:

- 1,400 kg/yr for deposition attributed to natural emissions;
- 230 kg/yr for deposition attributed to in-state anthropogenic emissions; and
- 1,600 kg/yr for deposition attributed to out-of-state anthropogenic emissions.

The load allocations for deposition attributed to natural emissions and anthropogenic emissions in and outside California incorporate reductions of 0%, 66% and 50%, respectively, compared to USEPA's REMSAD model output for 2001 atmospheric deposition. These reductions account for improvements in emission controls since 2001; inter-annual variability due to economic factors; and substantial emission reductions expected from recent and anticipated local, state, federal, and global rules and treaties.

Future work could include ARB, USEPA, and the State Water Board jointly developing a plan for how to evaluate changes in deposition patterns in California associated with local and global anthropogenic emissions. Using an adaptive implementation approach, the results of this evaluation could be used to identify and implement additional mercury controls for California emissions and/or additional national and international actions (a) if monitoring and modelling indicates the deposition load allocations likely will not be achieved, or (b) if new deposition hotspots are observed in California.

7.2.3 Urban Runoff

Potentially controllable processes

Urban runoff includes precipitation-induced stormwater runoff and irrigation runoff from landscaped areas. Anthropogenic mercury in urban runoff is primarily from atmospheric deposition from local and global anthropogenic emissions, versus discharges from local urban sources. Local urban sources can include improperly discarded fluorescent lights, thermometers, and other mercury-containing devices. Precipitation also may cause erosion of soils that naturally contain mercury. Runoff transports mercury attached to suspended sediment to surface waters, which in turn transports mercury-contaminated sediment to reservoirs where it settles on the bottom.

Mercury in urban runoff from local urban sources is controllable and actions to reduce mercury in runoff are already well underway. Mercury in urban runoff resulting from local use of mercury-containing products is expected to decrease to almost zero because the peak production and use of mercury-containing products occurred decades ago. Although mercury is still used in some products, new uses have largely been banned, and efforts to eliminate remaining uses are ongoing. Further, storm water discharge permits and other regulatory mechanisms require a combination of institutional controls and best management practices.

California's Mercury Reduction Act of 2001 (Senate Bill 633) limits the use of mercury in household products, schools, and vehicle light switches in California. The act directs the State's Department of Toxic Substances Control (DTSC) to provide technical assistance to local agencies and businesses, such as auto dismantlers, for the safe removal and proper disposal of mercury switches from vehicles and large appliances.

As a result of environmental regulations, U.S. manufacturers already are substituting less toxic compounds for mercury in devices, for example in thermometers and car alarms. Mercury use is expected to continue to decrease worldwide as a result of the recently ratified United Nations Minamata Convention on Mercury (www.mercuryconvention.org). Proper disposal of mercury-containing household devices such as fluorescent lights is increasing because more retailers are accepting discarded items, and manufacturers are implementing their "extended producer responsibility" programs.

Examples of institutional controls include recycling programs, street sweeping, and soil remediation at illegal dump sites and where local industrial use or spills polluted soils exposed to urban runoff. Institutional controls, along with careful application of best management practices (BMPs) during demolition and remodeling, have the potential to reduce the amount of mercury entering urban runoff from the remaining mercury-containing products to almost zero.

Several statewide and multi-state mercury TMDLs (e.g., Northeast States, Minnesota, New Jersey, and Florida) concluded that virtually all the mercury in urban runoff comes from atmospheric deposition, and direct discharges from local urban sources are expected to be reduced to virtually zero (CDEP 2007; MPCA 2007; NJDEP 2009; FDEP 2012). Their conclusions are supported by an extensive literature review and evaluation of local municipal and industrial mercury sources to San Francisco Bay area urban runoff and potential control methods conducted by several Bay area organizations (SFEI 2010; Davis et al. 2012).

One potential mercury source to urban runoff in some areas of California not addressed by the above-referenced reports is disturbance of historical mining waste by urban development activities. For example, Nevada City, a small town in the historic Gold Rush region of the Sierra Nevada (population of 3,068 people per the 2010 Census), is assessing five major mine tailings areas owned by the city. Supported by the USEPA's Brownfields Program, federal and local programs are collaborating with the city to evaluate mine tailings close to residential neighborhoods and four elementary schools (USEPA 2015; City of Nevada City 2015a and 2015b). After brownfields assessment and eventual cleanup, the brownfield sites will be used for publicly accessible greenspace and open space for recreational, educational, and ecological restoration purposes. Cleanup activities in Nevada City and other communities where development activities may disturb historical mining waste can include erosion control and remediation actions previously described in section 7.2.1 (Mine Sites and Mining Waste in Downstream Creeks).

Much of the mercury in atmospheric deposition cannot be controlled by local municipal agencies. As reviewed in earlier sections of this chapter, implementation of local air district, state, and federal emission rules and global treaties will be required to further reduce mercury in urban runoff. Nonetheless, urban sediment mercury concentrations are expected to decrease with reductions in global and local anthropogenic emissions and continued municipal control efforts.

In addition, the amount of atmospheric mercury deposition transported to surface waters by urban runoff is expected to decrease with increasing implementation of low impact development (LID) design standards in existing and future urban developments. The goal of LID is to limit hydromodification impacts from development. As noted in Chapter 6, urbanization traditionally increased the amount of impervious surfaces, which do not absorb water or trap pollutants like soil does. LID practices mimic a site's predevelopment hydrology by using design techniques that infiltrate, filter, store, evaporate, and detain runoff close to the source of rainfall (LID Center 2007; SWRCB 2013). These techniques reduce the amount of water and pollutants transported to surface waters. During the past ten years, NPDES MS4 and other stormwater permits and local ordinances throughout California have increasingly incorporated requirements for LID design standards.

Predictions for improvements

Including additional widespread sediment and mercury control requirements beyond those already included in existing MS4 permits is not expected to make measurable reductions in fish methylmercury concentrations in reservoirs included in this Reservoir Mercury Control Program for a number of reasons:

- As mentioned in the previous section, mercury in urban runoff resulting from local use of mercury-containing products is expected to decrease to almost zero because the peak production and use of mercury-containing products occurred decades ago. In addition, implementation of LID design standards is expected to reduce the amount of atmospheric mercury deposition transported to surface waters by urban runoff.
- The high population regions in California are downstream of all but a couple 303(d)-listed reservoirs. Most 303(d)-listed reservoir watersheds are rural with small isolated communities. With only three exceptions, there is very little urbanized land upstream of the 74 303(d)-listed reservoirs. Mercury in urban runoff in rural watersheds is expected to be almost entirely from atmospheric deposition rather than direct inputs from local urban sources. Consequently, implementation of additional widespread institutional controls and additional BMPs are not expected to measurably reduce mercury inputs from these urban areas.
- The three exceptions are Beach Lake, Puddingstone Reservoir, and El Dorado Park Lakes, where developed lands comprise about 20–30% of their watersheds. Only Beach Lake and Puddingstone have urban lands regulated by NPDES permits for MS4 discharges. The El Dorado Park Lakes are a chain of six small lakes within El Dorado Regional Park in the county of Los Angeles and do not have any organized storm drain network nor any permitted point sources in their watershed.
- The NPDES permits for MS4s that discharge upstream of Beach Lake and Puddingstone Reservoir already contain extensive and specific requirements for mercury control. These NPDES permits are:

- o NPDES Permit No. CAS082597 (Order No. R5-2008-0142): Waste discharge requirements for MS4 discharges from Cities of Citrus Heights, Elk Grove, Folsom, Galt, Rancho Cordova, Sacramento, and County of Sacramento; and

- o NPDES Permit No. CAS004001 (Order No. R4-2012-0175): Waste discharge requirements for MS4 discharges within the coastal watersheds of Los Angeles County.

Consequently, staff recommends a more focused approach that targets specific mercury sources that may not be adequately controlled by existing stormwater management programs. These include historical mining waste that may be disturbed by urban development activities and monitoring methylmercury production in stormwater conveyance systems.

Historical mining waste

As California's population continues to grow and new development takes place in regions impacted by historical mining activities, the risk of disturbing and transporting mining waste to surface waters also increases. Staff conducted a GIS-based review to assess the approximate number of communities that likely include historic gold, mercury, and silver mining features within their boundaries. As summarized in Appendix H (section H.3 and Table H.15), more than 100 communities may have mercury-contaminated mining waste within their boundaries. At least 74 of these communities encompass mining features upstream of a reservoir with elevated fish methylmercury levels. Of these 74 communities, 40 are subject to an NPDES MS4 permit; 33 are subject to the statewide NPDES Phase II small MS4 general permit, and 7 are subject to Phase I MS4 area-wide permits.

Of the 40 communities that are both subject to an NPDES MS4 permit and upstream of a reservoir with elevated fish methylmercury, 35 are upstream of at least one of the 74 reservoirs on the 2010 303(d) List for which TMDLs have not yet been adopted, and 5 are upstream of one of the other reservoirs with elevated fish methylmercury levels identified in Table 1.3 in Chapter 1.

Consequently, staff recommends that the implementation plan include requirements for MS4s that meet the following criteria to implement or cause to be implemented best management practices to minimize the transport of legacy mercury from historical mining operations to surface waters:

- The MS4 discharges are regulated by an NPDES permit;
- The MS4 discharges are upstream of a reservoir with elevated fish methylmercury levels; and
- The MS4 service area encompasses one or more historical mine sites, as identified by U.S. Geological Survey (USGS) topographical maps; USGS or other historical mine site databases; municipal or other historic records; or site inspections.

The proposed implementation plan would include requirements for MS4 NPDES permittees to require agencies and landowners implementing new road construction and maintenance activities, construction new development projects, or proposing changes in land use on land in areas potentially affected by historical mining operations to do the following:

- Submit a plan to the MS4 permittee that includes erosion estimates, erosion control practices, and, if a net increase in erosion is expected to occur, a remediation plan; and
- Implement practices to control erosion and minimize discharges of mercury.

There is precedence for this type of focused implementation approach. For example, the Cache Creek mercury TMDL implementation program requires landowners implementing new projects or proposing changes in land use in mercury-enriched areas to submit and implement erosion control and remediation plans (Cooke et al. 2005).

Methylmercury monitoring and adaptive management

staff recommends incorporating an adaptive implementation approach that includes requirements for monitoring methylmercury in urban runoff to determine whether dry season urban runoff contributes significantly to elevated levels of methylmercury in fish compared to other upland inputs to reservoirs with substantial watershed development (see section 7.2.6 in this chapter and section 9.5 in Chapter 9). We recommend re-evaluating urban runoff discharges during later phases to determine if additional total mercury and methylmercury reduction actions are necessary and feasible to achieve the proposed sport fish target.

Basis for allocation approach

TMDL allocations specific to mercury in urban runoff are not needed for two reasons:

- The atmospheric deposition source of mercury in urban runoff is accounted for in the load allocations for atmospheric deposition and will be reduced by actions taken to reduce local and global anthropogenic mercury emissions.
- The contribution of mercury to urban runoff from local use and improper disposal of mercury-containing products is expected to decrease to almost zero by the implementation of recent statewide mercury reduction rules. The many bans on new mercury use in California and the implementation of institutional controls and best management practices already included in existing NPDES MS4 permits and the above recommended requirements are expected to reduce this urban source of mercury to insignificant amounts. Additional best management practices for projects that disturb historical mining areas are expected to reduce mercury discharges from those areas.

There is precedence for this allocation approach. Mercury and other types of TMDLs have similarly not included allocations for urban runoff when it was considered a negligible source. For example, the Northeast State mercury TMDL report states:

> …the vast majority of mercury from stormwater that contributes to the impairment of these waters originates from air sources and should be controlled accordingly. Regulated stormwater is considered to be part of the de minimus WLA *[waste load allocation]*, and will be addressed through the controls on atmospheric deposition sources that are required to meet the load allocation. The states anticipate that once atmospheric deposition reductions are met, the only remaining regulated stormwater contributions would be solely attributed to natural sources and run-off from localized non-atmospheric sources. Given the states' commitment to virtual elimination of

> mercury, this residual stormwater contribution is considered to be a minute part of the WLA *[for NPDES-permitted discharges from facilities]*.

(CDEP 2007, page 29)

In addition, the Minnesota mercury TMDL, draft Florida mercury TMDL, Alamo River and New River sedimentation/siltation TMDLs, and New River pathogen and dissolved oxygen TMDLs did not include allocations for urban runoff because it was a negligible source (MPCA 2007; FDEP 2012; CRBRWQCB 2002a, 2002b, and 2002c; CRBRWQCB 2012).

Recommendations

Based on considerations and evaluations outlined in previous sections and chapters, staff recommends the implementation plan incorporate focused requirements for specific mercury sources that may not be adequately controlled by existing stormwater management programs. These include historical mining waste that may be disturbed by urban development activities and monitoring of methylmercury production in stormwater conveyance systems.

In addition, staff recommends an adaptive approach that includes re-evaluating urban runoff discharges during later phases to determine if additional total mercury and methylmercury reduction actions are necessary and feasible to achieve the proposed sport fish target. Staff does not recommend including widespread implementation requirements during the first phase for additional mercury source controls (beyond those already included in some existing NPDES permits for MS4 and industrial stormwater discharges) or TMDL allocations specific to urban runoff.

7.2.4 Runoff from Non-urbanized Upland Areas

Potentially controllable processes

Mercury is naturally occurring in soil and also present in soil from atmospheric deposition. Soil is erodible, and both natural and anthropogenic erosion result in soil being transported to surface waters. Anthropogenic erosion is controllable, and these control actions are called, simply, “erosion control.” Surface waters transport eroded soil to reservoirs where it settles on the bottom. In general, erosion control of watershed soils is unlikely to change reservoir sediment mercury concentrations. However, erosion control of mercury-contaminated hotspots, such as historical mine sites, is different and would likely reduce reservoir sediment mercury concentrations (see earlier sections).

As a rule, mercury source controls for non-urbanized and mined areas primarily have been associated with sediment management controls. An emerging research topic is mercury transport associated with dissolved organic carbon (DOC). Mercury mobilization to reservoirs for some land use types (wetlands and forestry) is associated with DOC of upstream and terrestrial origin, i.e., humic matter in the top layer of wetlands sediment and in topsoil (Watras 2009; Weiner et al. 2003). Hence, DOC is a factor in mercury transport to reservoirs.

Additionally, within reservoirs DOC is an important factor influencing mercury cycling (see section 4.1.1). Similar to soil erosion, both natural processes and anthropogenic activities can increase mobilization of DOC and mercury to surface waters. While controlling effects from natural processes would not likely be feasible, it could be possible to develop control actions that reduce anthropogenic increases in transport of DOC-linked mercury to reservoirs.

Predictions for improvements

Typical watershed erosion control methods are unlikely to reduce reservoir sediment mercury concentrations to levels lower than modern background. As with allocations for mine sites and mining waste, feasible soil mercury levels need to be considered when assigning allocations to watershed soils. Consequently, staff recommends the same modern background levels used to define TMDL allocations for mine sites and mining waste also be used to define TMDL allocations for watershed soils, by geographic region:

- Trace mercury areas: 0.1 mg/kg [dry wt., median]
- Mercury-enriched region: 0.3 mg/kg [dry wt., median]
- Mineralized zones: 400 mg/kg [dry wt., median]

These values take into account the variability in modern background levels in California's different mercury regions. The allocations would apply to runoff from non-urbanized upland areas; that is, the allocations would be for total mercury concentration in suspended sediment, i.e., particulate mercury.

Existing regulatory programs that require control of anthropogenic soil erosion. Soil erosion causes well-recognized water pollution problems, for example, fine sediment deposited in river beds where fish formerly spawned in gravels. The State and Regional Water Boards have many existing regulatory programs that address sediment pollution problems by requiring best management practices to control anthropogenic soil erosion. These programs simultaneously address mercury pollution where soil mercury levels exceed modern background levels. The Water Boards regularly identify and report waters impaired by sediment and/or siltation. The most recent report is the "2010 Integrated Report (Clean Water Act Section 303(d) List / 305(b) Report)" (SWRCB 2010c), which lists all water bodies in California known to be impaired by one or more pollutants. This "2010 303(d) List" contains 203 water bodies impaired by sediment and/or siltation, and 26 of these are in Category 4a (impairments are being addressed by USEPA-approved TMDLs). Subsequently, more sediment TMDLs have been completed (see Table H.6 in Appendix H) and more are planned.

In addition to sediment/siltation TMDLs, Regional Water Boards have other programs that will reduce sediment loads, which are listed in Table H.8. These regulatory tools include resolutions, orders, and NPDES permits that regulate stormwater discharges from construction, grazing, and timber harvesting activities. Other guidance, programs, and references that pertain to sediment or erosion control are listed in Table H.9.

Additionally, there are many statewide programs that will reduce sediment loads, examples of which are listed in Table H.10, such as general NPDES permits for urban runoff from large and small municipal stormwater systems (Phase 1 and 2 MS4s), stormwater discharges from construction activity (including small linear underground/ overhead construction projects), and conditional waivers of WDRs for grazing and for national Forest Service lands in California. These programs include various requirements, generally beginning with developing stormwater pollution prevention plans (SWPPPs), pollution prevention plans (PPPs) or pollutant minimization programs (PMPs); some require monitoring and reporting. These programs require responsible parties to implement BMPs appropriate for their activities and location.

Existing programs and policies for the control of anthropogenic sediment transport have widespread coverage of California, and a high level of expected improvement. Continued implementation of these programs, and continued assessment of water quality is expected to reduce soil erosion to levels that can be assimilated without impairing beneficial uses. Therefore, transport of sediment-associated inorganic mercury will be adequately controlled through widespread, existing erosion control programs.

Methods to reduce anthropogenic increases in transport of DOC-linked mercury. Mercury researchers are studying mercury transport from forestry and timber management and harvest operations. As noted earlier, it may be possible to develop control actions that reduce anthropogenic increases in transport of DOC-linked mercury to reservoirs. If so, such methods potentially could make substantial reductions in reservoir sediment mercury and fish methylmercury levels.

More than 20% of California is covered by forests, and the majority of forested areas in California are upstream of reservoirs. Forests are the primary land cover in many of the mercury-impaired reservoirs' watersheds. Thirty-three of the 74 303(d)-listed reservoirs have watersheds that are more than 50% forested, and eleven of those have watersheds that are more than 70% forested. Twenty-four of the 74 reservoirs have watersheds that are between 20% and 50% forested.

Forest canopies capture atmospheric mercury and translocate some of the metal to the forest floor in leaf litter. Forest soils tend to have higher mercury concentrations than soils in shrub and barren areas, likely because of the larger leaf surface area in forest canopies. Any land use that either increases erosion of mercury-contaminated leaf litter or increases surface water runoff from the leaf litter soil horizon has a high probability of increasing the amount of mercury transported to downstream rivers and reservoirs. In addition, forestry practices such as partial burning and logging can possibly increase off-site movement of DOC.

Studies conducted in boreal forests have linked mercury transport to increased DOC mobilization due to forestry practices, but mercury-specific transport from forestry practices in California has not yet been studied. This research may advance significantly during the course of the first phase.

Consequently, staff recommends allow time be allowed for the research on forestry management. The implementation plan should incorporate an adaptive approach that includes, during program review, performing an extensive review and analysis of scientific literature on the effects of forestry and timber management on methylation and fish methylmercury levels in downstream reservoirs and lakes. The literature review should include an analysis to determine whether additional studies are needed, and whether load allocations and best management practices are needed in later phases.

Recommendations

Based on considerations and evaluations outlined in previous sections for non-urban areas and mine sites, staff recommends the same modern background levels used to define TMDL allocations for mine sites and mining waste also be used to define TMDL allocations for watershed soils, by geographic region:

- Trace mercury areas: 0.1 mg/kg [dry wt., median]
- Mercury-enriched region: 0.3 mg/kg [dry wt., median]
- Mineralized zones: 400 mg/kg [dry wt., median]

In addition, staff recommends the implementation plan incorporate an adaptive approach that includes performing a review of scientific literature on the effects of forestry and timber management on methylation and fish methylmercury levels in downstream reservoirs and lakes. The literature review should provide an analysis of whether additional pilot tests are needed, and whether load allocations and best management practices or other implementation actions should be required for mercury transported by forestry and timber harvest activities. New requirements for controlling erosion of watershed soils are not necessary because transport of other watershed soils will be adequately controlled through existing, widespread erosion control programs.

7.2.5 Municipal and Industrial Facility Discharges

This section provides a review of potentially controllable processes and predictions for reductions of municipal and industrial wastewater facility mercury discharges. These provide the basis for staff's recommendations for waste load allocations and implementation plan requirements. The facility information evaluated in this section is from all NPDES-permitted facilities in California, not only to facilities that discharge directly to and upstream of the 74 reservoirs identified on the 2010 303(d) List. Including statewide information is consistent with the analysis in Chapter 6 (Source Assessment). This statewide facility information was used since effluent mercury data are not available for many facilities that discharge to or upstream of the 74 303(d)-listed reservoirs. This information is then used to develop waste load allocations for facility discharges directly to or upstream of reservoirs determined to be mercury-impaired.

Potentially controllable processes

More than half of NPDES-permitted facility discharges directly to or upstream of all reservoirs in California are from municipal wastewater treatment plants (WWTPs). Industrial dischargers upstream of reservoirs include manufacturing facilities, saw mills, and groundwater remediation facilities. Other types of facilities include power plants, fish hatcheries, drinking water treatment plants, geothermal utilities, and metal and nonmetal mine site discharges.

Mercury in municipal wastewater primarily comes from human waste and medical and dental facilities (Palo Alto RWQCP 1999). Nationwide, about half the mercury that enters municipal wastewater treatment systems comes from dental offices that do not use amalgam separators (USEPA 2014). Municipal wastewater treatment plants that discharge to inland waters in California provide either secondary or tertiary treatment. Secondary treatment generally includes settling, filtration, and biological treatment. Some plants also provide advanced secondary treatment, which removes additional solids. Tertiary treatment generally includes additional physical, chemical, and biological treatments to remove nutrients (phosphorus and nitrogen), organic matter, suspended solids, and toxic materials, and to disinfect the wastewater. Removing additional solids removes additional pollutants, like mercury, that adhere to particles. Facilities providing advanced treatment generally have better performance, hence lower effluent mercury concentrations than those providing secondary treatment. In addition, municipal WWTPs may implement mercury minimization programs and industrial pretreatment programs to reduce the amount of mercury in WWTP influent.

Mercury concentrations in industrial and other types of discharges depend on the types of activities in which these dischargers engage and on how they treat their waste streams. Treatment methods vary based on waste characteristics and may include use of settling basins, aeration, filtration, coagulants, oil-water separators, granular activated carbon, ion exchange resin, and treatment wetlands.

Predictions for improvements

As noted above, there are multiple methods for reducing mercury in facility discharges. However, the following findings indicate additional reductions in facility total (inorganic) mercury discharges upstream of reservoirs included in this Reservoir Mercury Control Program likely would not reduce reservoir fish methylmercury concentrations:

- There are over 500 individual NPDES permits for facility discharges throughout California, but less than 20% of facility discharges occur upstream of reservoirs (see Figure 6.26 in Chapter 6). Further, less than 5% of statewide permitted discharge volume is upstream of reservoirs. Of the 74 303(d)-listed reservoirs, 49 (about two-thirds) have no individually permitted facility discharges in their watersheds. This is not surprising given most 303(d)-listed reservoirs have very little urbanized area in their watersheds, as described in section 6.5.

- In addition, the linkage analysis described in Chapter 5 incorporated more than 20 factors related to the number and volume of facility discharges, ratio of facility discharge volume to reservoir inflows, annual and dry season effluent mercury loads, facility types, and wastewater treatment methods. None of these factors were correlated with reservoir fish methylmercury concentrations.

- Mercury in municipal and industrial wastewater influent is expected to decrease because the peak production and use of mercury-containing products occurred decades ago, and efforts to eliminate the remaining uses are ongoing. For example, the USEPA is proposing new technology-based pretreatment standards that would require dentist offices to use devices such as amalgam separators to remove mercury and other toxic metals before they are discharged to municipal wastewater systems (USEPA 2014). Many San Francisco Bay communities already have mandatory dental amalgam separator programs and have observed wastewater mercury reductions of nearly 75% (USEPA 2014). In addition, treatment upgrades implemented to address other pollutants (e.g., new ammonia effluent limitations and Title 22 or equivalent tertiary requirements) often decrease effluent mercury concentrations.

- Facility mercury discharges may be a substantial source to only one of the 74 303(d)-listed reservoirs, Beach Lake, in the greater Sacramento region. Further, the facilities upstream of Beach Lake likely already have very low effluent mercury concentrations, so reductions in NPDES facility discharges are not expected to make a measurable difference in Beach Lake fish methylmercury levels.

Other regional, statewide, and multi-state mercury TMDLs also came to the same conclusion that NPDES facilities contribute little to mercury impairments. Examples include the USEPA-approved San Francisco Bay, Northeast States, Minnesota, and New Jersey mercury TMDLs, and the draft Florida mercury TMDL (SFBRWQCB 2006; CDEP 2007; MPCA 2007; NJDEP 2009; FDEP 2012). The Northeast States, Minnesota, New Jersey, and Florida mercury TMDLs therefore established aggregate rather than individual allocations for facility discharges. Further, the New Jersey and Florida mercury TMDL aggregate allocations do not require reductions in facility mercury discharges.

This section focuses on NPDES-permitted facilities discharging to the 74 reservoirs on the 2010 303(d) List for which TMDLs have not yet been adopted. These facilities do not contribute substantial mercury to these reservoirs. However, this finding may not be true for facilities that discharge directly to or upstream of reservoirs determined to be mercury-impaired in the future, particularly those in more urbanized regions. Consequently, the TMDL allocation approach must take into account the reality that some facility discharges could be a substantial mercury source to an impaired reservoir, while other facility discharges are not.

Basis for allocations

Staff recommends that WLAs be designed to accomplish the following goals:

- Take into account that many dischargers already have implemented effective mercury control measures and are performing well.
- Apply more stringent limitations to discharges that are relatively large mercury contributors.
- Provide a consistent set of WLAs (and associated permit effluent limitations) that can be applied uniformly statewide now and in the future to facilities that discharge directly to or upstream of reservoirs identified as having elevated fish methylmercury concentrations.
- Ensure that facilities maintain proper operation, maintenance, and performance.

Additional considerations

There are several considerations for developing an effective TMDL WLA approach for NPDES-permitted facility discharges.

- The allocation approach should enable allocations to be included as numeric effluent limitations in NPDES permits in a straightforward manner, and take into account that many facilities may contribute only small amounts of mercury to an impaired reservoir.
- The allocation approach needs to apply to:
    - Current NPDES-permitted facility discharges to and upstream of 303(d)-listed reservoirs;
    - Expansion of current NPDES-permitted facilities;

   - Any new NPDES-permitted facility discharges to or upstream of these reservoirs that begin after the Reservoir Mercury Control Program is adopted; and
   - NPDES-permitted facility discharges to or upstream of reservoirs determined to be mercury-impaired in the future.
- The allocation approach should acknowledge good performance. State Water Board Resolution No. 2005-0060[1] required the San Francisco Bay Water Board to incorporate provisions that acknowledge the efforts of dischargers whose effluent quality demonstrates good performance, and require improvement by other dischargers, when establishing waste load allocations. Consequently, waste load allocations for the San Francisco Bay and upstream Delta TMDLs had calculation methods that took into account good performance (SFBRWQCB 2006; Wood et al. 2010b).
- All facilities that discharge to or upstream of impaired reservoirs need to have good effluent quality, and facilities that are large contributors to impaired reservoirs need to have excellent effluent quality.
- At the same time, facilities that make negligible contributions should not have to make costly improvements that result in no perceptible environmental benefit.

These considerations raise several questions that need to be addressed to develop effective waste load allocations:

- How do we define negligible dischargers?
- How do we define which dischargers are large sources of mercury to impaired reservoirs? (An intermediate category between negligible and large will be called "small dischargers.")
- How do we define good and excellent effluent quality and corresponding allocations?

Staff recommends the following definitions:

- Negligible dischargers: Dischargers subject to (a) State and Regional Water Board general NPDES permits, or (b) individual NPDES permits that have design discharge flows ≤0.2 million gallons per day (MGD).
- Small dischargers: Dischargers with individual NPDES permits that have either (a) design discharge flows >0.2 MGD and ≤1 MGD, (b) design flows >1 MGD but the sum of the NPDES-permitted facility discharges to or upstream of a reservoir does not exceed 1% of the reservoir inflow, or (c) unspecified flow volumes in the NPDES permits.
- Large dischargers: Dischargers with individual NPDES permits that have design discharge flows >1 MGD <u>and</u> the sum of the NPDES-permitted facility discharges directly to or upstream of a reservoir exceeds 1% of the reservoir inflow.

[1] Water Board resolutions are available at: www.waterboards.ca.gov/board_decisions/adopted_orders/resolutions/index.shtml.

- Good effluent quality (ng total mercury per liter, calendar year average):
  - Municipal WWTPs: ≤20 ng/L
  - Other types of facilities: ≤60 ng/L
- Excellent effluent quality (ng total mercury per liter, calendar year average):
  - Municipal WWTPs: ≤10 ng/L
  - Other types of facilities: ≤30 ng/L

Section H.4 in Appendix H provides a detailed description of options evaluated, statistical analyses, and rationale for how staff arrived at these recommended definitions. The following sections describe how these definitions form the basis for effective TMDL waste load allocations.

Proposed allocations

Staff recommends the following waste load allocation assignments (ng total mercury per liter, calendar year average):

- Large dischargers:
  - WLA for municipal WWTPs: 10 ng/L, annual average
  - WLA for other types of facilities: 30 ng/L, annual average
- Small dischargers:
  - WLA for municipal WWTPs: 20 ng/L, annual average
  - WLA for other types of facilities: 60 ng/L, annual average
- Negligible dischargers: Negligible dischargers are not assigned a WLA and can discharge without a WLA or corresponding permit effluent limitation for mercury.

These proposed WLAs could result in treatment upgrades or other actions for facilities that discharge effluent with mercury levels higher than WLAs.

Rigor and feasibility. To assess the rigor and feasibility of the proposed WLAs, staff evaluated the treatment performance of all facilities with an individual NPDES permit and effluent mercury data. Section H.4.4 in Appendix H provides an evaluation of effluent mercury data collected by facilities throughout the state (not just the facilities that discharges to and upstream of reservoirs). Of 116 municipal WWTP discharges evaluated:

- 97% have good performance, i.e., their calendar year average effluent mercury concentrations are less than 20 ng/L; and
- 94% have excellent performance, i.e., their calendar year average effluent mercury concentrations are less than 10 ng/L.

Of 36 other facilities evaluated (not including petroleum refineries and combined stormwater sewer systems), 100% have calendar year average effluent mercury concentrations less than both WLA values of 30 and 60 ng/L.

Conversely, 3% of the municipal WWTPs have at least one calendar year average effluent mercury concentration that exceeded the proposed WLA value of 20 ng/L, which indicates episodes of poor treatment performance. If any of these facilities were to discharge to or upstream of a mercury-impaired reservoir, they would be required to take actions to assess and reduce their effluent mercury concentrations.

Another 3% of the municipal WWTPs have at least one calendar year average effluent mercury concentration between 10 and 20 ng/L, which indicates episodes of good but not excellent treatment performance. If any of these facilities are classified as a large discharger to or upstream of a mercury-impaired reservoir, they also would be required to take actions to assess and reduce their effluent mercury concentrations.

This evaluation indicates that the proposed WLA approach is both rigorous and feasible.

<u>Absence of discharge or reservoir flow information.</u> In the absence of facility discharge or reservoir in-flow information, facility discharges should not be considered negligible by default. Some facilities with individual NPDES permits have intermittent discharges for which “design flow” is not defined in the permit. Staff recommends that, if an individual NPDES permit does not define “design flow,” maximum observed discharge may be used to classify a discharge. However, if no discharge flow data are available, staff recommends facility discharges should be classified as large by default, because this is the most environmentally protective assumption.

Appendix G summarizes available facility discharge and reservoir flow data for the 74 reservoirs on the 2010 303(d) List. We recommend that staff provide a technical report in the future that provides reservoir inflow data and upstream NPDES facility design flows for all reservoirs throughout California with upstream NPDES facility discharges. Such a technical report would act as a reference for permit writers as they incorporate WLAs in individual NPDES permits for facility discharges directly to or upstream of reservoirs determined to be mercury-impaired in the future. In the meantime, if no facility discharge data are available, this report employs the default of large discharger classification.

Proposed allocations for dischargers to and upstream of 2010 303(d)-listed reservoirs

This section describes how the proposed waste load allocations would be applied to facility discharges to and upstream of the 74 reservoirs on the 2010 303(d) List for which TMDLs have not yet been adopted. As described in Chapter 6, there are 47 NPDES-permitted facilities with 49 discharges to or upstream of the 303(d)-listed reservoirs. Ten of these facilities have design flows less than 0.2 MGD (see section 6.6.2 and Appendix G). The Chapter 6 source assessment determined that, of the 25 303(d)-listed reservoirs with at least one facility discharge in their watersheds, only one (Beach Lake) receives substantial inputs from facility discharges. These discharges are from four groundwater treatment facilities, two of which have discharges less than 1 MGD.

Using the WLA approach described in the previous section would result in the following WLA assignments for facility discharges to or upstream of 2010 303(d)-listed reservoirs, for municipal, industrial, and negligible dischargers:

- WLA of 10 ng/L for large municipal dischargers: 0 facilities

- WLA of 20 ng/L for small municipal dischargers: 17 facilities
- WLA of 30 ng/L for large industrial and other dischargers: 4 facilities
- WLA of 60 ng/L for small industrial and other dischargers: 18 facilities
- Negligible dischargers for which WLAs are not needed: 10 facilities

Chapter 8 provides tables that list the individual facility discharges and recommended WLA assignments for each. Where individual NPDES permits do not define “design flow,” staff used maximum observed discharge. If maximum observed discharge was not available, staff used average discharge or estimated discharge based on discharges from similar facilities to develop WLA assignments, rather than applying the default classification of large facility. Where no reservoir inflow data are available, staff used outflow data to develop WLA assignments. Neither inflow nor outflow information was available for two 303(d)-listed reservoirs with upstream NPDES facility discharges: San Pablo Reservoir and Anderson Reservoir. For this draft report, Water Board staff applied the classification of large facility for NPDES facility discharges upstream of these reservoirs. *Note to readers: Water Board staff encourages NPDES permittees, reservoir owners and operators, and other stakeholders to provide Water Board staff with accurate discharge and inflow data, for staff to use to finalize this report.*

Two facilities have multiple discharges to 2 different 303(d)-listed reservoir watersheds. The Castaic Power Plant discharges to both Castaic Lake and Pyramid Lake via its discharges to Elderberry Forebay. Its discharges are comprised almost entirely of noncontact cooling water. Its discharges are counted just once in the above list, with a WLA assignment of 60 ng/L, because NPDES facilities are small contributors of mercury to both Castaic Lake and Pyramid Lake.

In addition, the Aerojet Interim Groundwater Extraction and Treatment Systems have several discharge points, two of which are in the Lake Natoma and Beach Lake watersheds. NPDES facilities are small contributors of mercury to Lake Natoma; therefore, the Aerojet discharge upstream of Lake Natoma is included in the count for small industrial discharges, with a WLA assignment of 60 ng/L. However, NPDES facilities may contribute more substantially to Beach Lake, particularly during the dry season. Further, the Aerojet discharge to Morrison Creek upstream of Beach Lake has a design capacity of more than 1 MGD. Consequently, the Aerojet discharge upstream of Beach Lake is included in the count for large industrial discharges, with a WLA assignment of 30 ng/L.

The assessment of NPDES facility discharges upstream of Beach Lake was particularly conservative for several reasons (see section 6.6.2). Consequently, the proportion of facility mercury inputs to Beach Lake compared to other sources (e.g., atmospheric deposition) is almost certainly over-estimated. Hence, facility discharges might only exceed the 1% threshold during the dry season. <u>This is a draft report</u>. Consequently, dischargers and other stakeholders may continue to provide additional information that could change understanding of the significance of NPDES facility inputs to Beach Lake and other mercury-impaired reservoirs. Staff will adjust the proposed WLA assignments as needed based on new information received before the report is finalized.

Recommendations

Based on considerations and evaluations outlined in previous sections, staff recommends the following approach for TMDL waste load allocation assignments for facilities that discharge to or upstream of mercury-impaired reservoirs:

- Large dischargers: Dischargers with individual NPDES permits that have design discharge flows >1 MGD, and the sum of the NPDES-permitted facility discharges to or upstream of a reservoir exceeds 1% of the reservoir inflow.
    - o WLA for municipal WWTPs: 10 ng/L (calendar year average)
    - o WLA for other types of facilities: 30 ng/L (calendar year average)

  Small dischargers: Dischargers with individual NPDES permits that have either (a) design discharge flows >0.2 MGD but ≤1 MGD, (b) design flows >1 MGD but the sum of the NPDES-permitted facility discharges to or upstream of a reservoir does not exceed 1% of the reservoir inflow, or (c) unspecified flow volumes in the NPDES permits:
    - o WLA for municipal WWTPs: 20 ng/L (calendar year average)
    - o WLA for other types of facilities: 60 ng/L (calendar year average)
- Negligible dischargers: Dischargers subject to (a) State and Regional Water Board general NPDES permits, or (b) individual NPDES permits that have design discharge flows equal to or less than 0.2 MGD. Negligible dischargers are not assigned a WLA and can discharge without a WLA or corresponding permit effluent limitation for mercury.

For WLA compliance monitoring, staff recommends the following:

- Compliance points be the effluent monitoring points described in individual NPDES permits.
- Unfiltered effluent total mercury samples be analyzed, at a minimum, with a method detection limit of 0.2 ng/L and a reporting level of 0.5 ng/L.
- Effluent total mercury monitoring frequency should be based on an understanding of treatment system variability and variability of effluent mercury concentrations. For example, more frequent (monthly) monitoring could be required for facility discharges with highly variable mercury concentrations that approach or exceed the WLA, and less frequent (quarterly or semi-annual) monitoring could be required for facility discharges with very low mercury concentrations (e.g., calendar year average mercury concentration less than 5 ng/L).
- Power, heating/cooling, fish hatcheries, and other facilities with intake water from the same water body as their receiving water body conduct concurrent monitoring of their intake water and effluent discharge. Methods described in the Policy for Implementation of Toxics Standards for Inland Surface Waters, Enclosed Bays, and Estuaries of California (SWRCB 2005) should be used to assess potential for intake water credit.

Staff also recommends requirements for monitoring methylmercury in facilities that uses one or more treatment pond systems (e.g., oxidation, facilitative, settling, or stabilization ponds) to determine whether facility discharges contribute significantly to elevated levels of methylmercury in fish. We recommend re-evaluating facility discharges during later phases to determine if additional total mercury and methylmercury reduction actions are necessary and feasible to achieve the sport fish target.

Finally, we recommend that staff provide a technical report in the future that provides reservoir inflow data and upstream NPDES facility design flows for all reservoirs throughout California with upstream NPDES facility discharges. Such a technical report would act as a reference for permit writers as they incorporate WLAs in individual NPDES permits for facility discharges directly to or upstream of reservoirs determined to be mercury-impaired in the future.

7.2.6 Watershed Methylmercury Sources

The linkage analysis determined that reservoir water methylmercury concentrations, in addition to sediment and water inorganic mercury concentrations, are strongly correlated to reservoir fish methylmercury concentrations. In addition, as noted in later sections, the Reservoir Mercury Control Program may need to incorporate reduction strategies specific to methylmercury sources in addition to inorganic mercury source control actions because inorganic mercury reduction alone may not achieve the proposed sport fish target in many reservoirs.

There is inadequate information about tributary methylmercury concentrations and watershed methylmercury sources to include these potential factors in the linkage analysis and source assessment in Chapters 5 and 6. Further, the literature reviewed in Chapter 4 provides evidence that much of the methylmercury in reservoir water is produced within reservoirs.

Nonetheless, potential controls and predictions for watershed methylmercury sources are reviewed in this section for two reasons:

- There is the potential for watershed inputs to be a substantial source to some reservoirs, especially reservoirs with short residence (water retention) times.
- In the future, when more methylmercury data are available for watershed inputs, the need for and feasibility of additional methylmercury allocations can be evaluated through the program's adaptive implementation process.

Watershed sources include both nonpoint sources and point sources, discussed separately below.

Nonpoint sources

Nonpoint methylmercury sources include methylmercury production in riverine water column, channel sediment, wetlands, and upstream reservoirs, and runoff from urban areas outside of MS4s and non-urban upland areas. River channels and wetlands make up a tiny portion of the watersheds of the 74 reservoirs identified on the 2010 303(d) List for which TMDLs have not yet been adopted. Figure 4.2(A) in Chapter 4 displays estimated methylmercury loading rates for catchments containing a variety of land uses, including agriculture, forests, and urban areas. The methylmercury loading rates for these upland landscapes are about a magnitude less per unit area than loading estimates for methylmercury production within reservoirs (Figure 4.2(B)). Consequently, this program focuses on in-reservoir methylation.

Nonetheless, reducing inorganic mercury sources likely will result in reducing methylmercury production and discharges from terrestrial and aquatic environments. Reducing total mercury from sources such as atmospheric deposition, mining, and gross industrial contamination is a viable and effective way to reduce methylmercury production in wetted soils and sediments. Also, as noted in section 7.2.4, staff recommends continued assessments of emerging research about mercury transport associated with dissolved organic carbon. However, mercury source control cannot reduce mercury below naturally occurring levels in watershed soils; some of this mercury will become methylated and transported to reservoirs.

Point sources

Discharges from urban areas served by MS4s, municipal WWTPs, and other types of facilities contain methylmercury in addition to inorganic mercury (Bosworth et al. 2010; SJ/SC 2007; Parmer et al. 2005; Bodaly et al. 1998; McAlear 1996; Gilmour and Bloom 1995; Goldstone et al. 1990; Wood et al. 2010b; Mason and Sullivan 1998; Tetra Tech 2005a; Waldron et al. 2000; Henry et al. 1995; Babiarz et al. 1998).

MS4 discharges. Methylmercury concentrations ranged from a wet weather low of 0.035 ng/L to a dry weather high of 2.04 ng/L in MS4 discharges from Sacramento, Stockton, and Tracy urban areas, with many sample results exceeding methylmercury concentrations in corresponding receiving waters (Wood et al. 2010b, Figure H.2). Even so, the average annual methylmercury loading rate for these urban areas and urban catchments elsewhere in the United States are comparable in magnitude to loading rates observed for other types of upland landscapes (Figure 4.2(A) in Chapter 4). However, dry season MS4 inputs are a more relevant input to assess.

As noted in Chapter 2, most of California is marked by only two distinct seasons, a dry season and a rainy (or snow) season. Natural runoff tends to be minimal during the dry season, but MS4 flows tend to be proportionally greater due to landscape irrigation and other urban inputs. Higher temperatures and longer days during the dry season may contribute to greater mercury methylation rates as the runoff flows through storm water conveyances. In addition, high bioaccumulation periods typically occur in reservoirs in the dry season (summer and fall). Consequently, there is the potential for dry season MS4 discharges to make comparatively greater contributions to fish methylmercury levels than analysis on an annual basis would indicate.

Additional information is needed to evaluate point sources that are a significant source of methylmercury to the reservoir and control of these methylmercury discharges may result in measurable reservoir fish methylmercury reductions. The focus should be on mercury-impaired reservoirs that have watersheds that are more than 20% developed and there is a developed MS4 storm drain network that conveys urban runoff into the reservoir or its tributaries.

Two of the 74 303(d)-listed reservoirs have watersheds that are more than 20% developed and have storm drain networks that convey urban runoff into the subject reservoirs or their tributaries. Puddingstone Reservoir, located between the cities of San Dimas and Pomona in the greater Los Angeles area, and Beach Lake, located in the greater Sacramento region, both have watersheds that are about 30% developed (see section 6.5.2). Two Phase 1 MS4 NPDES permits regulate urban runoff in the watersheds of these reservoirs:

- NPDES Permit No. CAS004001 (Order No. R4-2012-0175): Waste discharge requirements for MS4 discharges within the coastal watersheds of Los Angeles County; and
- NPDES Permit No. CAS082597 (Order No. R5-2008-0142): Waste discharge requirements for MS4 discharges from Cities of Citrus Heights, Elk Grove, Folsom, Galt, Rancho Cordova, Sacramento, and County of Sacramento.

However, there is currently not enough information about methylmercury concentrations in urban runoff and tributary inflows to, and methylmercury production within, Beach Lake, Puddingstone Reservoir, and other reservoirs with substantial upstream urban development to determine whether reducing methylmercury concentrations in urban runoff would result in measurable fish methylmercury reductions.

Consequently, staff recommends requiring monitoring of methylmercury in representative urban runoff discharges (and other inputs to these reservoirs) to mercury-impaired reservoirs or their tributaries. Specifically, staff recommends requiring monitoring for MS4s that meet the following criteria:

- The MS4 serves more than 100,000 people; and
- The MS4 conveys urban runoff into a mercury-impaired reservoir or its tributaries where more than 20% of the reservoir watershed has urban development.

This monitoring could be coordinated with reservoir owners/operators and other stakeholders so the relative magnitude of methylmercury in urban runoff can be determined and compared to other reservoir inputs, including in-reservoir production.

Staff recommends an adaptive implementation approach that includes review of urban runoff methylmercury monitoring results during program review. The review should determine if additional methylmercury data are needed and whether methylmercury allocations and control actions are necessary and feasible during the later phases to achieve the proposed sport fish target.

There is precedence for including methylmercury monitoring and control requirements in TMDL control programs. Both the San Francisco Bay and Delta mercury control programs included methylmercury monitoring requirements for MS4s. In addition, the Delta mercury control program required large MS4s to conduct methylmercury control studies.

Facility discharges. Bosworth and others (2010) evaluated effluent methylmercury concentration data for municipal wastewater treatment plants as well as 12 categories of non-municipal facilities in California's Central Valley downstream of major reservoirs. Almost all non-municipal facilities had very low (<0.05 ng/L) or nondetectable effluent methylmercury concentrations.

In contrast, municipal WWTPs had more variable effluent methylmercury concentrations. A third of the 61 municipal WWTPs evaluated had very low (<0.05 ng/L) or nondetectable average effluent methylmercury concentrations, while about a third had average effluent methylmercury concentrations greater than 0.2 ng/L. A small number of WWTPs (7) had average concentrations greater than 1 ng/L. Municipal WWTPs that used one or more of the following treatment processes generally had lower effluent methylmercury concentrations: nitrification/denitrification, filtration, and ultraviolet (UV) disinfection. These treatment processes are often employed to address pollutants other than methylmercury. Municipal WWTPs that used one or more treatment pond systems (e.g., oxidation, facultative, settling, or stabilization ponds) had significantly higher effluent methylmercury concentrations.

Plant upgrades made for reasons other than mercury may reduce discharges of methylmercury. For example, upgrades to the City of Stockton WWTP completed in September 2006 to meet new ammonia effluent limitations and Title 22 (or equivalent) tertiary requirements appear to have led to reductions in total mercury and methylmercury as well as ammonia (Wood et al. 2010b). Before the upgrades, the City of Stockton WWTP treatment processes included advanced secondary treatment with high-rate trickling filters and secondary clarifiers, followed by unlined facultative oxidation ponds, dissolved air flotation, mixed-media filters, and chlorination/dechlorination facilities. The September 2006 upgrades included the addition of two nitrifying biotowers and engineered wetlands to remove ammonia from the waste stream. The City of Stockton WWTP was also upgraded to meet Title 22 tertiary requirements, which included new tertiary filters and new facilities to provide coagulation, flocculation, and sedimentation prior to filtration.

Since the City of Stockton WWTP was upgraded, average effluent methylmercury concentrations decreased by 91% (0.08 ng/L average, seven monthly samples), average inorganic mercury concentrations decreased 83%, and average ammonia concentrations decreased by 95%, as shown by a comparison of before (August 2004–July 2005) and after (January–July 2009) data (Wood et al. 2010b; Figure 7.4). (Note, it is not known if the treatment plant upgrades are responsible for the methylmercury and mercury reductions, or if the reductions are a result of other operational or physical changes. Additional sampling may be needed to determine the cause of the decrease.)

As with urban runoff (described in previous section), there is the potential for NPDES facility discharges during the dry season to make comparatively greater contributions to fish methylmercury levels than an annual analysis of inorganic mercury inputs would indicate. Further, it makes sense to evaluate point sources where their control may result in measurable reservoir fish methylmercury reductions, i.e., facility discharges that are relatively large (design flow >0.2 MGD) and are likely to have elevated effluent methylmercury concentrations. As noted earlier, facilities that use one or more treatment pond systems (e.g., oxidation, facilitative, settling, or stabilization ponds) are the most likely to have elevated effluent methylmercury concentrations.

Of the 47 individually-permitted facilities that discharge to or upstream of the 74 303(d)-listed reservoirs, 8 have design discharges that exceed 0.2 MGD <u>and</u> are likely to have elevated effluent methylmercury concentrations (Table G.1 in Appendix G).

There currently is not enough information to determine whether reducing methylmercury concentrations in treatment pond systems (e.g., oxidation, facilitative, settling, or stabilization ponds) would measurably reduce fish methylmercury. Consequently, staff recommends requiring monitoring of methylmercury in discharges from facilities with treatment pond systems.

Staff recommends an adaptive implementation approach that includes the review of facility methylmercury monitoring results after the first phase. The review should determine if additional methylmercury data are needed and whether methylmercury allocations and control actions are necessary and feasible during the later phases to achieve the proposed sport fish target.

There is precedence for including methylmercury monitoring and control requirements in TMDL control programs. Both the San Francisco Bay and Delta mercury control programs included methylmercury monitoring requirements for NPDES facilities. In addition, the Delta mercury control program required NPDES facilities to conduct methylmercury control studies.

Recommendations

Based on considerations and evaluations outlined in previous sections, staff recommends the monitoring of methylmercury in the following NPDES-permitted discharges and their receiving waters:

- Discharges from MS4s that serve more than 100,000 people and convey urban runoff to a reservoir or its tributaries where more than 20% of the reservoir watershed has urban development; and
- Discharges from individually-permitted facilities with treatment pond systems.

This monitoring could be coordinated with reservoir owners/operators and other stakeholders so the relative magnitude of methylmercury in these discharges can be determined and compared to other reservoir inputs, including in-reservoir production, particularly during seasons of highest bioaccumulation (e.g., late spring through fall).

Staff recommends an adaptive implementation approach that includes the review of methylmercury monitoring results before the later phases. The review should determine if additional methylmercury data are needed and whether methylmercury allocations and control actions are necessary and feasible during the later phases to achieve the proposed sport fish target.

7.2.7 Predictions for Improvement Based on Source Control

Location and timing of improvements

As noted at the beginning of section 7.2, mercury concentrations in fish at contaminated industrial sites around the world declined after implementing control measures to reduce incoming mercury loads (Figure 7.1). 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. After which, concentrations tend to stabilize with little, if any, subsequent decline (Turner and Southworth 1999; Takizawa 2000; Lodenius 1991; Lindestrom 2001; Francesconi et al. 1997).

Earlier sections of this chapter identified staff predictions of which source control activities may lead to measurable reductions in methylmercury concentrations in fish (resulting from reductions in sediment mercury concentrations). Table 7.1 identifies staff predictions for each of the 74 reservoirs on the 2010 303(d) List for which mercury control programs have not yet been adopted; Table H.1 in Appendix H summarizes supporting information and describes any additional assumptions made. Figure 7.5 illustrates the location of six 303(d)-listed reservoirs where we predict quick reductions, three from remediation of mining waste and three from controlling local air emissions.

Mining sources. Largely absent from the literature are reports on remediation of pollution from mercury and gold mining. Recovery likely will be much slower than at industrial sites, given the magnitude and duration of mercury and gold mining in California, coupled with the extensive distribution of contamination from both direct discharges and atmospheric deposition associated with emissions from historic processing activities. Using assumptions developed in section 7.2.1, Figure 7.5 and Table 7.1 identify the three reservoirs where we predict relatively quick improvements may occur from remediation of mining waste. Conversely, we predict much slower improvements resulting from mining waste remediation in 37 reservoirs (Table 7.1). Further, we predict substantial improvements to result from mining waste remediation in only 8 of these 37 reservoirs.

Atmospheric deposition. Fish methylmercury levels could decline in approximately a decade in those lakes and reservoirs that receive most of their mercury in the form of direct deposition (Harris et al. 2007). Such reservoirs have a relatively large surface to watershed area ratio and no point sources. However, for all other lakes and reservoirs, there may be some initial decline in fish methylmercury as a result of reduced direct deposition, but it could take decades to centuries for substantial reductions in response to the re-equilibration of upland soils as stored industrial-era mercury is depleted (Watras 2009; Golden and Knightes 2008; Harris et al. 2007; Perry et al. 2005; Lorey and Driscoll 1999; Mason et al. 1994).

Only 3 of the 74 303(d)-listed reservoirs are expected to have relatively quick improvements from controlling local air emissions: El Dorado Park Lakes, Indian Valley Reservoir, and Puddingstone Reservoir. These reservoirs (Figure 7.5 and Table 7.1) have no other substantial anthropogenic mercury sources in their watersheds and receive most of their water from within their watersheds (i.e., no water imports).

Conclusions

The predictions outlined in this chapter indicate reducing anthropogenic mercury sources in California may result in measurable reductions in methylmercury concentrations in fish (or measurable reductions in mercury concentrations in reservoir sediment) in about 60% of the 74 reservoirs on the 2010 303(d) List for which TMDLs have not yet been adopted (Table 7.1). Conversely, these predictions indicate the Reservoir Mercury Control Program may need to rely entirely on reservoir chemistry and fisheries management to make fish methylmercury reductions in about 40% of these reservoirs. These predictions support the conclusions of the linkage analysis and source assessment in Chapters 4 and 5. We cannot rely on source control alone to achieve the proposed sport fish target in all reservoirs, especially if we want to make timely improvements. This supports staff’s earlier recommendation that the implementation plan for the Reservoir Mercury Control Program should include reservoir and fisheries management components in addition to a source control component. Further, these predictions highlight the need for allocations for in-reservoir methylmercury production because achieving proposed allocations for inorganic mercury sources is not expected to achieve the proposed sport fish target in many impaired reservoirs.

7.3 Within-Reservoir Methylmercury Production

The conceptual model (Chapter 4) provides evidence that much of the methylmercury that is bioaccumulated by biota is produced within the reservoir. Importantly, bioconcentration of methylmercury from water to phytoplankton (trophic level 1) is many orders of magnitude greater than biomagnification of methylmercury up the food web. Consequently, reducing methylation of mercury may be the most effective way to reduce methylmercury in fish.

The conceptual model describes factors that influence methylation in the aquatic environment. While it may not be feasible to control some factors, others may be controllable, such as anoxia, redox potential, and contaminated sediments. These are discussed individually in the following sections.

Most reservoirs likely will require multiple actions. Table 7.1 and section 7.3.5 summarize where staff predicts one or more actions may be effective at reducing fish methylmercury concentrations in the 74 reservoirs on the 2010 303(d) List for which TMDLs have not yet been adopted.

7.3.1 Anoxia

Potentially controllable processes

Anoxic conditions in the aquatic environment can stimulate methylmercury production as well as affect other water quality parameters. Reducing the degree, extent, or duration of anoxia in the hypolimnetic waters of a reservoir may suppress mercury methylation and discharge to the hypolimnion in some reservoirs. Management practices to increase oxygen levels in reservoirs include artificial circulation, hypolimnetic aeration, and hypolimnetic oxygenation (Beutel and Horne 1999; Cooke et al. 1986).

Artificial circulation can be achieved by the use of pumps, jets, and bubbled air to mix the water column, prevent stratification, and increase oxygen levels in reservoirs. However, because artificial circulation often disrupts thermal stratification, the temperature of the hypolimnion is increased. Consequently, artificial circulation would not be a feasible control process for reservoirs required to maintain a cold water pool for downstream releases.

In contrast, hypolimnetic aeration or oxygenation techniques can increase oxygen levels in the hypolimnion while minimally affecting thermal stratification in a reservoir. Both techniques can decrease methylmercury production in reservoirs and lakes. For example, the Santa Clara Valley Water District observed significant reductions in seasonal maximum concentrations of methylmercury in the hypolimnion at Lake Almaden, California, after installation of solar-powered circulators (Figure 7.6) (Drury 2011). The circulators were not effective at reducing oxygen depletion or methylmercury production in larger reservoirs in the Guadalupe River watershed. The District is currently testing the effects of hypolimnetic oxygenation in these other reservoirs.

Washington State University researchers performed an oxygenation study on the North and South Twin Lakes; both had similar summer hypolimnetic oxygen depletions and aqueous methylmercury enrichment prior to the study. North Twin Lake was treated with hypolimnetic oxygenation, while South Twin Lake was left untreated as an anaerobic control (Dent et al. 2014; Beutel et al. 2010 and 2014; Reed 2011). Hypolimnetic oxygen depletion in North Twin Lake was suppressed by oxygenation, and methylmercury concentrations were reduced approximately ten-fold compared to the previous year. Untreated South Twin Lake had similar hypolimnetic anoxia and high aqueous methylmercury concentrations in both sampling years.

However, zooplankton methylmercury levels from North Twin Lake were elevated when compared to South Twin Lake zooplankton. The researchers demonstrated that the oxygenation apparatus, which was designed to increase fish habitat and not inhibit methylation, did not provide complete oxygenation at the sediment–water interface (Dent et al. 2013 and 2014; Beutel et al. 2014). This allowed continued, albeit less, methylmercury production at the sediment–water interface and allowed methylmercury to mix into a greater portion of the lake. Though the concentration of aqueous methylmercury was lower in the hypolimnion of the treated lake, methylmercury became more bioavailable because the biota was able to reside deeper in the oxygen-enriched hypolimnion.

The authors concluded that hypolimnetic oxygenation may be a viable mechanism to reduce methylmercury production; however, care must be taken in the design of the system to ensure oxygen saturation occurs in the zone where methylation occurs. This did not occur in North Twin Lake because the gas bubbles are less dense than water and so float upwards. There are other types of oxygen delivery systems, such as Speece cones, that likely perform better than bubblers in this regard.

Reservoir aeration, circulation, hypolimnetic aeration, and hypolimnetic oxygenation are currently in use to address other water quality problems in California reservoirs, such as Camanche Reservoir, Big Bear Lake, Upper San Leandro Reservoir, and Indian Creek Reservoir (Beutel and Horne 1999; Brown and Caldwell 2010). These reservoirs include a large range of sizes, from 1,500 to 417,000 acre-feet. Increasing hypolimnetic oxygen in California reservoirs addresses several concerns, including but not limited to increasing fish habitat and reducing phosphorus, phosphate, nitrate, ammonia, hydrogen sulfide, and manganese pollution. Notably, these systems were not installed to address mercury.

In summary, it is possible that multiple water quality impairments could be addressed by reservoir oxygenation management practices. Evidence suggests that reducing anoxic conditions in the hypolimnion of some reservoirs could reduce methylmercury production; however, concomitant methylmercury reductions in biota have yet to be observed from oxygenation.

Predictions for improvements

Reservoir oxygenation management practices may be particularly effective at reducing fish methylmercury levels in reservoirs that have strong anoxia, particularly at the sediment-water interface. Reservoirs in the Coast Ranges and southern California often have strong thermal stratification, and hence anoxia at the sediment-water interface. The 74 303(d)-listed reservoirs include 28 reservoirs in the Coast Ranges and 8 in southern California with such characteristics (Table H.1). In addition, the limited data set summarized in Table H.1 indicates several Sierra Nevada reservoirs—Camanche, Camp Far West, Folsom, McClure, New Melones, and Oroville reservoirs—also have exhibited depressed dissolved oxygen levels (<5.0 mg/L) in their hypolimnia. Consequently, more than half of the 74 303(d)-listed reservoirs may benefit from oxygenation management practices (Table 7.1). Even in very large reservoirs, where we anticipate it could be cost-prohibitive to implement oxygenation management practices over the entire reservoir, we expect that targeted application of management practices in high-methylation areas will reduce fish methylmercury concentrations.

7.3.2 Redox Potential

Potentially controllable processes

Suppressing mercury methylation in the hypolimnion has been accomplished in reservoirs by adding nitrate to adjust the redox potential. For example, Onondaga Lake in New York was polluted from a legacy of industrial and municipal discharges prior to passage of the Clean Water Act. As a result, the lake was closed to recreational fishing because of elevated fish methylmercury levels. Operations at the municipal wastewater treatment plant were upgraded by adding a nitrification process. This upgrade resulted in increased discharges of nitrate to the lake that increased the nitrate concentration in the lake by two-fold. Todorova and others (2009) observed a 50% decrease in aqueous methylmercury accumulation in the lake when nitrate was present above the sediment–water interface. They hypothesized that nitrate might control methylmercury accumulation in anoxic conditions through (1) the suppression of the activity of sulfate-reducing bacteria and subsequent methylation, (2) a decrease in the methylation/demethylation ratio, or (3) a decrease in the mobilization of metal oxide bound methylmercury from the sediment.

Because of the observed suppression of methylation due to the presence of nitrate, calcium nitrate has been applied to reservoirs to suppress mercury methylation in the hypolimnion. For example, in Onondaga Lake, researchers conducted a whole lake pilot test of nitrate treatments that reduced maximum aqueous methylmercury concentrations by 94% (Matthews et al. 2013). The success of the nitrate pilot test in Onondoga Lake prompted full-scale nitrate addition as a long-term management practice to reduce methylmercury production in Onondaga Lake (Driscoll et al. 2013).

Similar suppression of methylation was observed in a pilot test at Round Lake, Minnesota. Austin and others (2013) applied liquid calcium nitrate to the bottom of the lake to increase the redox potential. When the nitrate concentrations in the hypolimnion were above 0.5 mg/L, methylmercury production was suppressed. After the nitrate in the lake was depleted, methylmercury production resumed back to levels similar to their control lake.

Management practices that adjust the redox potential in reservoirs may possibly be able to reduce methylmercury concentrations in fish. Nitrate additions can increase the redox potential; however, such additions might increase primary production in reservoirs that are nitrate limited. Recognizing this possible adverse consequence, researchers were careful to apply either neutrally buoyant liquid nitrate solution near the bottom of Onondaga Lake or viscous and dense liquid nitrate solution that sank to the bottom of Round Lake. Additionally in Onondaga Lake, the stoichiometry and timing of nitrate additions is monitored closely so nitrate is fully consumed before fall overturn.

Nonetheless, nitrate additions may not be possible in reservoirs that are nitrate limited and at risk of excessive primary production (eutrophication). Pilot tests for minimal nitrate additions should be conducted in California reservoirs that are not primary drinking water supplies before implementing a more widespread program to ensure no adverse impacts to drinking water objectives. In addition, any nutrient addition program for reservoirs should consider downstream conditions to ensure any potential increase in nitrates in reservoir releases do not negatively impact downstream conditions. Conversely, some reservoirs (and downstream rivers) may benefit from increased primary production resulting from nitrate addition. Increasing primary production in reservoirs as a potential management practice is discussed in a later section of this chapter.

Predictions for improvements

Nitrate additions to increase redox potential may be particularly effective at reducing fish methylmercury levels in reservoirs for the same reasons as described previously for oxygen, namely strong anoxia, particularly at the sediment-water interface. Consequently, about half of the 74 303(d)-listed reservoirs may benefit from minimal nitrate additions. It could be cost-prohibitive to implement nitrate additions over the entirety of very large reservoirs; even so, we expect that targeted application in high-methylation areas will reduce fish methylmercury concentrations.

7.3.3 Within-Reservoir Sediment Mercury

Reservoirs themselves are not sources of inorganic mercury. However, they are often deposition sites for mercury-contaminated sediment from watershed sources that can in turn increase methylmercury production in reservoirs.

Potentially controllable processes

Reservoirs are efficient at trapping sediment and hence sediment-associated chemicals and contaminants. For some reservoirs, methylmercury production possibly can be reduced by lowering mercury concentrations in the bottom sediment by removing or capping contaminated sediment. Sediment removal is an effective reservoir management technique when properly conducted (Cooke et al. 1986).

Thus, an obvious solution to the problem of contaminated sediment is removal, but removal is frequently complicated by secondary pollution (mercury and other pollutants) of the overlying water column through sediment agitation during the removal process. Sediment dredging and removal often is necessary for some reservoirs because incoming sediment reduces the reservoirs' water storage capacity, and the buildup of sediment can disrupt access in marinas.

Sediment capping works by effectively making the mercury not bioavailable by burying it with clean, uncontaminated sediment or other cap material. *In situ* sediment capping has been a feasible and cost effective method for on-site remediation of contaminated sediment at multiple sites throughout the world (Ling and Leshchinsky 1998).

Sediment removal and capping will likely only be effective once upstream sources of mercury are addressed because otherwise the reservoir bottom sediment will be re-contaminated by continued upstream sources. Stabilization of in-stream mining waste, in addition to mine site remediation, is an important step in reducing downstream reservoir fish methylmercury levels, as recently evidenced by a recent cleanup effort at Peña Blanca in Arizona. Even after upstream mine sites and in-reservoir mining waste were remediated, tributary inputs to Peña Blanca still had elevated suspended sediment mercury concentrations, indicating that in-stream mining waste is an important source (Curiel 2013; ADEQ 1999).

Further, sediment removal or capping may not be effective or feasible for mercury reduction in some reservoirs. For instance, it may not be effective to remove sediment in reservoirs that have sediment mercury concentrations near watershed (background) soil mercury concentrations (see Chapter 6). In addition, it may not be feasible in some reservoirs to reduce capacity, even slightly, by capping contaminated sediment. Capping would reduce the amount of storage in reservoirs for flood control and water.

Also, a short-term adverse effect of sediment removal actions is an increase in the short-term bioavailability of mercury from re-suspension of sediment during dredging. In addition, there could be a short-term spike in water and fish methylmercury caused by the re-wetting of reservoir soils when the reservoir is re-filled after sediment removal or capping activities.

In summary, sediment removal and capping can remove mercury from some reservoirs. Some of these actions can be taken in conjunction with (or after) upstream source controls to reduce the amount of mercury that is available for methylation and bioaccumulation in reservoirs. Some current reservoir non-mercury specific management practices may be effective at removing mercury from reservoirs, too, such as periodic dredging for marina access or storage capacity.

Predictions for improvements

Sediment removal or capping after upstream source remediation may be effective at reducing fish methylmercury levels in reservoirs where:

- There is extremely contaminated reservoir sediment in either a portion of a reservoir (if the reservoir is large) or throughout the reservoir (if the reservoir is small), and
- The primary source of contamination is located near the reservoir (e.g., within 10 km upstream of the reservoir) and has been remediated.

If contamination sources are near the reservoir, there will not be tens or hundreds of miles of creek channels with highly contaminated sediment that can be difficult or impossible to remediate. Conversely, if contamination sources are far upstream, or if the contamination comes from industrial air emissions that result in mercury deposition across a watershed, then reservoir sediment removal or capping could be confounded by the continued input of contaminated stream sediments and watershed soils, which is further considered in section 7.6.

At least 3 of the 74 303(d)-listed reservoirs may have these conditions and therefore might be amenable to sediment removal or capping in the foreseeable future. We arrived at 3 by the following desktop analysis.

<u>Step 1</u>: Is reservoir sediment extremely contaminated, i.e., five times greater than elsewhere in a given reservoir or extremely contaminated compared to typical values for its geographic region?

(a) For larger reservoirs, a minimum of three sample locations is needed for this step; 17 of the 74 303(d)-listed reservoirs have at least three sample locations (Table H.1). Of these 17 reservoirs, 4 reservoirs have at least 1 location with sediment mercury five times greater than elsewhere in the reservoir.

(b) Several smaller reservoirs have only one or two sediment samples each but these were extremely contaminated; five reservoirs meet this criterion (Table H.1).

Mining waste is the primary source of contamination to the 9 reservoirs that meet the criteria for (a) or (b).

<u>Step 2</u>: (a) Are the contamination sources localized to a relatively small area within the reservoir watershed? Three of the 9 reservoirs that meet the Step 1 criteria have localized mine sites: Lake Nacimiento, Marsh Creek Reservoir, and Davis Creek Reservoir. (b) Are the localized contamination sources located no more than 10 km upstream, or otherwise have short sediment travel distance to the reservoir? (See Table H.1 in Appendix H for details.) Of the three reservoirs from Step 2.a, Davis Creek Reservoir and Lake Nacimiento meet this criterion.

<u>Step 3</u>: Are there reservoirs where no sediment mercury data are available but there are other indicators that sediment removal or capping might be a viable option? For example, no sediment mercury data are available for Lake Herman, but Hastings Mine is located upstream. Staff inspected Hastings Mine in 2008 and determined it presents a low risk of erosion of mercury-laden mining wastes to Sulphur Springs, which drains into Lake Herman (SFBRWQCB 2009). Further, staff did not observe mining waste in channels adjacent to and immediately downstream of Hastings Mine (SFBRWQCB 2009). Staff hypothesizes that mining waste has already been mostly washed downstream into the reservoir. If true, and if reservoir sediment has elevated mercury from mining, sediment capping or removal may be effective at reducing methylation in Lake Herman.

In conclusion, after upstream mine and creek remediation are completed, sediment removal or capping may be effective for at least three reservoirs: Lake Nacimiento, Davis Creek Reservoir, and Lake Herman. However, these in-reservoir actions may not be necessary. Natural erosion from other areas of the reservoir watershed, transported in stormwater, will eventually bury the mercury-contaminated sediment. Importantly however, if the timescale of this natural process is too long, then sediment removal or capping should be undertaken to speed up the recovery process.

7.3.4 Other Potentially Controllable Methylation Factors

Increase photodemethylation

Photodemethylation can be a major loss pathway of methylmercury in water bodies. Photodemethylation is dependent on ultraviolet light intensity, residence time, and methylmercury concentration. In turn, increasing light penetration in reservoirs could help reduce methylmercury concentrations in water. Possible ways to increase light penetration include reducing turbidity, reducing DOC, and reducing algae in eutrophic reservoirs. Likewise, increasing the residence time (water retention) of reservoirs can possibly reduce aqueous methylmercury concentrations by exposing methylmercury to sunlight longer.

Raise pH of acidic reservoirs

Reservoirs with lower pH tend to have higher rates of methylation and higher levels of methylmercury in fish. Thus, increasing pH of acidic reservoirs may decrease methylmercury production (or bioaccumulation, see section 5.4.3). Mailman and others (2006) propose that addition of lime could be useful to reduce methylmercury concentrations in reservoirs with low pH. In addition, reducing emissions of pollutants that produce acid rain (e.g., NO_x, SO_x) might increase pH in reservoirs and thereby reduce methylation (Watras 2009).

Lime additions could be particularly useful in reservoirs with inputs of acid mine drainage or naturally acidic soils. Emission reductions could result in methylation reductions in reservoirs downwind of substantial industrial and urban emissions.

Reduce emissions of sulfur dioxide

Reducing emissions of pollutants might have a more direct effect in reducing methylation by reducing sulfate concentrations in reservoirs. For example, sulfur dioxide is transformed to sulfate in the atmosphere, which means that emissions of sulfur dioxide can increase the amount of sulfate in reservoirs. Sulfate is necessary for high rates of mercury methylation.

Based on experiments of sulfate additions in simulated rainfall on peatlands that increased mercury methylation, Coleman-Wasik and others (2011) hypothesize that reducing sulfate loads from atmospheric deposition could result in rapid reductions of methylmercury production in wetlands. Therefore, reducing SO_x emissions might reduce methylmercury production both in upstream wetlands and within California reservoirs.

7.3.5 Predictions for Improvement Based on Reservoir Water Chemistry Management

Earlier sections identified staff predictions of where different types of reservoir water chemistry management practices might lead to measurable fish methylmercury reductions. Table 7.1 identifies predictions for each reservoir and Appendix H describes any additional assumptions. As illustrated by Table 7.1, reservoir water chemistry management practices are predicted to measurably reduce fish methylmercury in more than half of the 74 303(d)-listed reservoirs for which mercury control programs have not yet been developed.

Many potential management practices described in previous sections have been employed elsewhere in the world but not in California, or if in California, not for the specific purpose of reducing reservoir fish methylmercury concentrations. In addition, the predictions are based on limited data sets.

Even so, the predictions, combined with the conceptual model findings and linkage analysis, indicate additional pilot tests and associated studies are warranted. Reservoir water chemistry management practices have the potential to make measurable improvements in many reservoirs, and to do so relatively quickly (e.g., in less than 10 years). Consequently, staff recommends that owners and operators of mercury-impaired reservoirs included in the Reservoir Mercury Control Program complete individual or coordinated pilot tests of methylmercury controls in reservoirs. The purpose of the pilot tests would be to develop effective and economically feasible technologies and management practices to reduce reservoir fish methylmercury concentrations.

These pilot tests should (a) characterize methylmercury production and bioaccumulation in reservoirs, (b) include pilot tests of reservoir management practices to reduce methylmercury production, and (c) be coordinated with fisheries managers to include pilot tests of fisheries management practices to reduce bioaccumulation. The pilot tests and associated studies should assess effectiveness, costs, and potential public and environmental benefits, and negative impacts. After the pilot tests and associated studies are completed, they can be evaluated to determine which reservoirs in California are amenable to different management practices.

There is precedence for incorporating pilot test and study requirements in TMDL control programs in California. The San Francisco Bay, Guadalupe River watershed, Walker Creek watershed, and Delta mercury TMDLs all include an adaptive implementation approach, study requirements, and other voluntary studies by regulated dischargers, reservoir owners/operators, and wetland managers.

7.3.6 Basis for a Methylmercury Allocation for Methylmercury Production

This section describes the need and basis for a methylmercury allocation for in-reservoir methylmercury production. The conclusions of the linkage analysis and source assessment in Chapters 4 and 5 were that we cannot rely on source control alone to achieve the proposed sport fish target, especially if we want to make timely improvements. In other words, achieving the recommended allocations for inorganic mercury sources outlined in section 7.2 is not expected to achieve the proposed target in many impaired reservoirs.

Consequently, TMDL allocations are needed for in-reservoir methylmercury production as well as for inorganic mercury sources (both upstream and upwind sources). For reasons provided in section 7.2.6, staff recommends assigning TMDL allocations to in-reservoir methylmercury production but not to watershed methylmercury sources at this time. Nonetheless, reducing inorganic mercury sources that contaminate watershed areas where methylation takes place is expected to reduce nonpoint methylmercury sources that contribute to downstream reservoirs.

Staff recommends the TMDL allocation for in-reservoir methylmercury production be set equal to the statewide goal proposed in section 5.2.3: no detectable aqueous methylmercury in unfiltered reservoir water (calendar year median for the entire water column, including the epilimnion and hypolimnion) at a detection limit not exceeding 0.009 ng/L. Based on data and linkage model predictions described in Chapter 5, achieving this proposed allocation is expected to achieve compliance with the proposed sport fish target in about 70% of mercury-impaired reservoirs.

This prediction is based on reducing in-reservoir methylmercury production alone, and does not account for the effect of watershed mercury source reduction or fisheries management actions. Model predictions described in Chapter 5 and Appendix B indicate a reduction of mercury sources to near zero anthropogenic inputs (i.e., the proposed load and waste load allocations for mercury sources), in conjunction with reducing in-reservoir methylmercury production, will achieve the proposed targets in California's impaired reservoirs. In addition, the model predictions do not preclude the possibility that an aqueous methylmercury concentration of 0.009 ng/L (or higher) may be adequate for all reservoirs to achieve the proposed targets. In the future, through an adaptive implementation approach, the methylmercury allocation can be reconsidered and if needed, a revised methylmercury allocation can be proposed.

Staff recommends the allocation for in-reservoir methylmercury production be implemented as a management practice. We recommend this because it is likely possible to reduce fish methylmercury levels by mercury source controls and fisheries management practices without specific in-reservoir actions to reduce reservoir aqueous methylmercury concentrations.

Staff also recommends a study to develop an analytical protocol that consistently achieves an analytical method detection limit (MDL) of 0.009 ng/L or lower. A lower MDL would help refine understanding of in-reservoir methylmercury production and degradation, which could be useful for developing methylmercury management practices. MDLs consistently lower than 0.02 ng/L are already possible, as evidenced by the following:

- USEPA Method 1630 states that an MDL of 0.009 ng/L for methylmercury in water should be analytically achievable, if a laboratory uses "extra caution in sample handling and reagent selection, particularly the use of 'for ultra-low level only' distillation equipment" (USEPA 2001c).
- The Marine Pollution Studies Laboratory achieved an MDL of 0.005 ng/L using USEPA method 1630 with (a) extra caution in sample handling and reagent selection, and (b) distillation equipment designated for ultra-low level samples only (Byington 2012).
- Brooks Rand Labs[2] states that they consistently achieve an MDL of 0.01 ng/L using USEPA method 1630 (Brooks Rand Labs 2010 and 2012). In addition, Brooks Rand Labs states that they recently achieved an MDL of 0.005 ng/L using USEPA method 1630 combined with rigorous equipment preparation measures prior to distillation (Brooks Rand Labs 2015).
- The USGS laboratory in Wisconsin uses USEPA method 1630 with isotope-dilution for methylmercury determinations. Laboratory staff found the addition of isotope dilution

[2] Brooks Rand Labs was recently re-named to Brooks Applied Labs, see: http://brooksrand.com/

greatly improves MDLs, decreasing the MDL by more than half, from 0.02 ng/L to 0.01 ng/L, and frequently as low as 0.005 ng/L (Krabbenhoft 2014).

There is precedent for control programs including TMDL allocations for methylmercury production. The Guadalupe River and Walker Creek watershed mercury TMDLs assigned allocations to in-reservoir methylmercury production (SFBRWQCB 2008a and 2008b). In addition, the Delta mercury TMDL assigned allocations to methylmercury production within open channels (Wood et al. 2010a and 2010b).

7.3.7 Recommendations

Based on considerations and evaluations outlined in previous sections and chapters, staff recommends a TMDL allocation be assigned to in-reservoir methylmercury production because inorganic mercury control alone is not expected to achieve the proposed fish methylmercury targets in every reservoir. Staff recommends the allocation be no detectable aqueous methylmercury in unfiltered reservoir water (calendar year median for the entire water column, including the epilimnion and hypolimnion) with a detection limit not exceeding 0.009 ng/L. The allocation should be implemented as a management practice with the goal of achieving the proposed sport fish target.

In addition, staff recommends owners and operators of mercury-impaired reservoirs included in the Reservoir Mercury Control Program complete individual or coordinated pilot tests of methylmercury controls in reservoirs. The purpose of the pilot tests would be to develop effective and economically feasible technologies and management practices to reduce reservoir fish methylmercury concentrations. Results would be incorporated in the Reservoirs Mercury Control Program using an adaptive implementation approach.

Finally, staff recommends a study take place to develop an analytical protocol that consistently achieves an MDL of 0.009 ng/L or lower for methylmercury in water. Results of the study, and future data collected using lower MDL analytical methods, can be used to revise the allocation for in-reservoir methylmercury production as needed, using an adaptive implementation approach.

7.4 Fisheries Management

In addition to controlling processes to reduce in-reservoir methylmercury production, it also may be possible to reduce methylmercury bioaccumulation. The primary mechanism that could control bioaccumulation and biomagnification in reservoirs is adjusting the food web. This section first considers controls at the bottom of the food web, namely increasing primary production, and then considers fisheries management to reduce biomagnification in higher trophic levels. The section then finishes by discussing other potentially controllable bioaccumulation factors.

7.4.1 Increases in Primary Production

Potentially controllable processes

Increasing the quantity or quality (nutritional value) of reservoir algae can result in decreased fish methylmercury concentrations through biodilution. As described in the conceptual model (Chapter 4), biodilution takes place through two mechanisms, algal bloom dilution and somatic growth dilution.

First, through algal bloom dilution, an increase in algal biomass can reduce the concentration of methylmercury in algal tissue at the base of the food web (assuming no change in in-reservoir methylmercury production). This results in a decrease in methylmercury concentrations per unit tissue throughout the food chain. Second, through somatic growth dilution, an increase in primary production increases available food at the base of the food web, which increases the growth rates throughout the food web. In addition to abundance of food, the quality of food influences somatic growth dilution. When there are sufficient food resources to allow an organism's growth rate to increase to a level where biomass is assimilated faster than methylmercury, then somatic growth dilution can occur. Chapter 4 and Appendix A provide examples of where these two biodilution mechanisms have been observed in laboratory and field studies.

Nutrient addition programs have been in place for over two decades in British Columbia and elsewhere to increase primary production in lakes and rivers and restore important recreational and commercial fisheries (Stockner and Macisaac 1996). The programs increased growth rates, abundance, biomass, and survival at all trophic levels. Though the programs were not developed to reduce methylmercury concentrations in biota, it is likely that increased primary and secondary production decrease methylmercury bioaccumulation through biodilution.

Predictions for improvements

As described in more detail in Appendix A, increasing primary production may be effective at reducing reservoir fish methylmercury levels where reservoirs are oligotrophic (chlorophyll concentrations less than 3 µg Chl/L). Chlorophyll information is available for 35 of the 74 303(d)-listed reservoirs (Table H.1). Of these 35 reservoirs, 21 (60%) have geometric mean chlorophyll concentrations less than 3 µg Chl/L. In addition, 4 of the reservoirs for which chlorophyll data are not available also may be oligotrophic, as indicated by predatory fish with low growth rates (see Tables H.1 and H.14 in Appendix H). Albeit, 1 of these 4 reservoirs (Del Valle) was recently enrolled in the Statewide General NPDES Permit for Residual Aquatic Pesticide Discharges to Waters of the United States from Algae and Aquatic Weed Control Applications (Order 2013-0002-DWQ, NPDES Permit CAG990005), which indicates the reservoir may not be oligotrophic. In addition, reservoirs with short residence times, such as Oxbow Reservoir, may not be amenable to nutrient management.

These multiple types of information indicate low chlorophyll levels (and cultural oligotrophication; see Appendix A) may be causing or contributing to the mercury impairment of at least 21 reservoirs. These 21 reservoirs could be candidates for a nutrient management program. These reservoirs are widely distributed across the state and are in the Coast Ranges, Trinity Alps, and low and high elevations in the Sierra Nevada Mountains.

However, to maintain the basic oligotrophic character of a reservoir, nutrient additions should not increase ambient chlorophyll levels more than two-fold (see Appendix A for literature review). Staff developed a multiple linear regression equation to predict the chlorophyll concentration associated with a predatory fish methylmercury concentration of 0.2 mg/kg (Appendix A, Part 5). The regression equation predicts that >75% of the candidate reservoirs with geometric mean chlorophyll concentrations less than 3 µg Chl/L would need about a doubling or less in chlorophyll to meet the proposed sport fish target. The remaining reservoirs would require additional mercury control actions to meet the proposed sport fish target.

Based on these results, staff recommends additional studies and pilot tests at representative reservoirs in California to determine the feasibility of using nutrient additions to reduce fish methylmercury concentrations.

7.4.2 Stocking Practices

Potentially controllable processes

Stocking is the repeated input of hatchery-raised fish. Fisheries can be managed to reduce fish methylmercury levels through stocking efforts because stocking can cause somatic growth dilution in higher trophic levels of the food web. Currently, this may be an indirect effect of DFW's stocking rainbow trout in California reservoirs. Chapter 4 and Appendix A provide examples of where fisheries management actions have been observed to reduce methylmercury and other bioaccumulatives in fish.

Stocking is a common practice in California reservoirs. It may be possible to adjust stocking practices to reduce fish methylmercury concentrations, while still providing recreational sport fishing. For example, low-mercury rainbow trout are widely stocked in California reservoirs and may already increase the size of predatory sport fish such as brown trout and black bass, while reducing their methylmercury concentrations. Additional stocking might further decrease those methylmercury concentrations, and future stocking programs might spread these benefits to more California reservoirs.

Additional practices also could include stocking other types of low-methylmercury prey fish for reservoir predator fish to consume, and stocking types of sport fish that have less methylmercury (e.g., rainbow trout and catfish instead of bass). Hatcheries may need to be modified to accommodate changes. Potential innovative practices also could include, but are not limited to, the following:

- Relying on hatcheries that supply low methylmercury fish for either:
    - Stocking larger predator fish into reservoirs where they will not become self-sustaining populations[3]; or

[3] Methylmercury concentrations in predatory fish are highly responsive to prey contamination, and more than half of methylmercury burden (mass) in predatory fish is due to the most recent one or two years of growth (e.g., Greenfield et al. 2008; Melwani et al. 2009; Trudel and Rasmussen 2006; Stafford and Haines 2001; Harris

- o Stocking large, sterile predator fish. (Note that triploid rainbow trout are sterile and are already widely stocked in California (DFW 2013), but rainbow trout are not predator fish.)

Humans and wildlife would benefit from lower mercury risk by consuming either the low-methylmercury stocked rainbow trout or predatory sport fish with low methylmercury concentrations. Likewise, the larger sport fish would be an additional benefit for recreational catch-and-release fishers.

Predictions for improvements

Stocking practices in mercury-impaired reservoirs might be changed to increase the abundance of fish with lower methylmercury levels. Changing stocking practices may be particularly effective at reducing reservoir fish methylmercury levels where predatory sport fish are regularly stocked, or stocking of low-methylmercury prey fish could reduce methylmercury levels in resident predatory sport fish.

Of the 74 303(d)-listed reservoirs, available fish methylmercury data and recent stocking information (i.e., for stocking within the last five years) indicates that 47 (64%) have been recently stocked with fish (Table 7.1 and Table H.1 in Appendix H). Reservoirs that are stocked with predatory sport fish may be amenable to changes in stocking practices. (These changes may involve any one or multiple of the practices described in the previous section.) Thirty reservoirs (41%) have been recently stocked with predatory sport fish such as black bass and brown trout, or other lower trophic level species that often have elevated methylmercury levels, such as catfish and Chinook and Coho salmon (Table H.1).

Reservoirs that are stocked with low methylmercury fish may be amenable to new stocking practices that provide even more low-methylmercury prey fish for resident predatory fish. Forty-five (61%) have been recently stocked with fish that typically have low methylmercury levels, such as rainbow trout and Kokanee salmon(Table H.1). (Of these 45 reservoirs, 28 were stocked with species that often have elevated methylmercury levels. These 28 overlap with the 30 reservoirs in the above paragraph.)

Of the 47 recently stocked reservoirs, 29 have methylmercury data for one or more of the stocked species (Table H.1); it is not possible to tell from these data whether the fish (other than rainbow trout) accumulated methylmercury at the hatchery or in the reservoir (because hatchery fish methylmercury data are available only for hatchery rainbow trout [FMP 2005 and 2007]).

- 15 of these 29 reservoirs have at least one stocked species with average methylmercury concentrations that exceed the proposed sport fish target. Fisheries management activities such as no longer stocking predatory fish, stocking large predatory fish with low methylmercury levels, or providing low methylmercury prey fish are worth considering for these reservoirs.

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and Bodaly 1998). Consequently, if stocked large predator fish are not quickly caught by anglers and wildlife, within about two years we would expect their mercury concentrations to be comparable to resident predator fish.

- 22 of these 29 reservoirs have at least one stocked species (rainbow trout and/or kokanee salmon) with average methylmercury concentrations that are below the proposed sport fish target. Fisheries management activities such as providing additional low methylmercury prey and sport fish are worth considering for these reservoirs.

Also, 44 (59%) of the reservoirs apparently have not recently been stocked with predatory fish or other species that often have elevated methylmercury levels (Table H.1). Of these 44, available fish methylmercury data indicates that 43 have resident predatory fish with elevated methylmercury concentrations.[4] Fisheries management activities such as providing additional low methylmercury prey and sport fish are worth considering for these reservoirs.

The above findings indicate several of the 74 303(d)-listed reservoirs may be amenable to changes in current stocking practices, or new stocking practices that provide low methylmercury prey fish for resident predatory fish (Tables 7.1 and H.1). However, as noted in Table H.1, there are also several reservoirs where stocking has recently ceased due to potential negative impacts to downstream Endangered Species Act listed species and their habitat, and to downstream fish hatcheries. Based on these results, staff recommends additional studies and pilot tests at representative reservoirs in California to evaluate the potential for modifying stocking practices to reduce reservoir fish methylmercury concentrations.

7.4.3 Intensive Fishing

Potentially controllable processes

Intensive fishing could be used to increase fish growth rates and remove methylmercury from lakes (Mailman et al. 2006). This has been demonstrated in field studies by Gothberg (1983) and Verta (1990). In both studies, intensive fishing removed about half of the biomass of the top predator fish species. The result was that the remaining predators' growth rates doubled for several years. Mass balance calculations estimated that the mass of methylmercury per individual fish remained the same as before intensive fishing; however, the biomass of each fish doubled, resulting in decreased methylmercury concentrations on a tissue basis. In addition, as described in Chapter 4, intensive fishing can remove a substantial proportion of methylmercury from a reservoir system, reducing the methylmercury available to the remaining biota.

Intensive fishing (harvesting) currently is practiced in some California reservoirs. For example, Big Bear Municipal Water District has an ongoing carp harvest program to decrease nutrients in Big Bear Reservoir, which has a surface area of about 3,000 acres. The carp are removed to improve the desired trout fishery and reduce eutrophication induced by nutrients released by carp stirring up bottom sediments. The carp are removed using an electroshocking boat and an annual carp round-up contest. It is possible that a large proportion of methylmercury is removed

[4] Note: 2 of the 47 reservoirs do not have predatory fish methylmercury data that indicate elevated levels (see Table H.1 in Appendix H). In Thermalito Afterbay, largemouth bass has an average methylmercury concentration of 0.20 mg/kg, and all other sampled species have lower methylmercury concentrations. Only low-trophic level fish, Sacramento sucker and hitch, were sampled in Lake Solano, and sucker average methylmercury concentration exceeds 0.20 mg/kg.

from Big Bear Lake by periodic carp harvests. However, no studies have yet been performed in California reservoirs to evaluate the effects of intensive fishing on fish growth rates and methylmercury concentrations, or the amount of methylmercury removed from a reservoir system.

Predictions for improvements

Intensive fishing may be particularly effective at reducing reservoir fish methylmercury levels where reservoirs are oligotrophic, as indicated by low chlorophyll levels or predatory fish with low growth rates, e.g., as indicated by the fish age to length regressions (see Tables H.1 and H.16 in Appendix H). Intensive fishing may also be particularly effective where predatory fish such as black bass and brown trout—but not prey fish—have elevated methylmercury concentrations. (This results in fewer predators competing for low methylmercury prey fish.) Intensive fishing of carp also may be a useful way to remove methylmercury from reservoirs where carp are one of the primary species present with elevated methylmercury concentrations, and where carp is a low-value fish compared to other fish present in the reservoir
Of the 74 303(d)-listed reservoirs, available information indicates that 48 (65%) meet one or more of these conditions (Table H.1).

However, the size of a reservoir also needs to be considered. For large reservoirs like Oroville and Folsom (both have surface areas >10,000 acres), a sustained effort to remove possibly tens of thousands of fish may be needed to improve the growth rates of remaining fish (J. Rowan 2014, pers. comm.). If 11 large reservoirs (>5,000 acres) are excluded, then intensive fishing may be effective at reducing fish methylmercury levels at about half (37) of the 74 303(d)-listed reservoirs (see Tables 7.1 and H.1).

Further, intensive fishing may be best if utilized as a one-time effort in combination with other management practices. Intensive fishing could "reset" sport fish methylmercury levels that would then be maintained by other management practices. One-time intensive fishing of popular sport fish would minimize impacts to recreation.

7.4.4 Other Potentially Controllable Bioaccumulation Factors

In this section we consider more speculative options for controlling methylmercury bioaccumulation.

Change fish assemblages. There are several potential ways that changing fish assemblages could reduce bioaccumulation. These include supplanting or removing fish species that accumulate more contaminants with species that accumulate less contaminants, and reducing the length of the food chain.

Supplanting fish species was described by Stow, et al. (1995) as a fisheries management practice to reduce fish polychlorinated biphenyl (PCB) levels. Stow hypothesized a 78% reduction in PCB concentration by replacing lake trout with rainbow trout. Rainbow trout grow faster, have a shorter lifespan, and eat a more diverse diet than lake trout. These factors reduce PCB accumulation and, likewise, could be translated into methylmercury reduction.

Additionally, Stow et al. discussed trophic cascade management to reduce PCB concentrations. In this concept, the food chain is managed by reducing the number of piscivorores. Therefore, the forage fish populations increase leading to increased zooplankton foraging. The decreased zooplankton abundance causes an increase in algal biomass leading to algal bloom dilution. Algal bloom dilution occurs when a constant mass of contaminant is distributed among a larger biomass of algae. The result is a lower concentration of contaminant per unit of algal food (see Appendix A). While Stow focused on fish PCB concentration, the concept could be translated into methylmercury management strategies. Reducing the length of the food chain could be effective because bioaccumulation occurs with each step in the food chain, and so shorter chains have less bioaccumulation.

In the last decade, the California Department of Fish and Wildlife was successful in removing the predatory and invasive northern pike (*Esox lucius*) from Lake Davis (DFW 2014a). This was accomplished by administering the chemical rotenone to the lake, and has resulted in restoring the (stocked) rainbow trout fishery. Rainbow trout sampled in July and August 2008 had methylmercury concentrations of 0.03 – 0.04 mg/kg, while brown bullhead had methylmercury concentrations of 0.06 – 0.08 mg/kg (all data date from after eradication of northern pike; Appendix Z).

In contrast to northern pike that impaired the recreational trout fishery in Lake Davis, black bass are a popular sport fish in many reservoirs across California, as are striped bass in some reservoirs. Like northern pike, bass are predatory and invasive, and bass are the fish species that most frequently has elevated methylmercury levels in California reservoirs. Northern pike may have been somewhat easily eradicated because it is a much more recent introduction to California than bass (1980's and 1990's for pike compared to late 1800's for bass (Moyle 2002; DFW 2014b). However, bass and many other non-native fish species introduced to California for recreational purposes are now self-sustaining populations. Bass fisheries are a popular recreational activity important to many local economies. Staff considered the potential for removing bass from reservoirs that have other valuable recreational fish, or do not derive economic benefit from bass, however people have mentioned that bass fishers are known to stock bass themselves. Additionally, the measures to eradicate bass would likely kill all fish and many other species in the reservoirs. For these reasons, and recognizing the economic importance of the bass fishery, staff does not propose that fisheries management studies evaluate the removal of bass.

Nonetheless, it may be possible to supplant long-established, self-sustaining, piscivorous species (e.g., black bass, brown trout, and striped bass) with lower trophic level fish species. However, such supplanting of other species over bass may require concerted efforts including extensive stocking and restoration of native anadromous fisheries (e.g., steelhead and salmon) in many reservoirs. Supplanting could be reassessed in the future via a literature review.

The length of the food chain has a strong influence in the overall accumulation of methylmercury in reservoirs and lakes. Longer food chains cause greater bioaccumulation. By definition, shortening food chain lengths requires eradication or replacement of species at one level in the food chain. At this time, we are not aware of any such targeted eradication or replacement efforts. Reducing the food chain length could be reassessed in the future via a literature review.

<u>Catch restrictions</u>. Size and bag limits are a common form of regulation to allow both take of sport fish and protect fisheries by ensuring that reproducing adults or a large portion of the population are not taken. For example, most reservoirs in California have a 12-inch minimum size limit for black bass and a five-fish daily bag limit. Changing size limits, e.g., establishing "slot limits" that specify a safe size range of fish for consumption, could reduce human consumption of larger, older fish with high methylmercury levels. Such a change in catch restrictions would reduce human, but not wildlife, bioaccumulation of methylmercury. However, care would need to be taken to ensure reproduction-age fish are not negatively impacted. Care would also need to be taken to establish slot limits that reflect site-specific fish methylmercury-to-length relationships, and to provide outreach and education to increase and enforce angler compliance with the limits.

Note that catch restrictions are unlikely to conflict with the Trophy Black Bass program, which provides the opportunity for anglers to catch and release trophy-sized black bass at designated waters. The Trophy Black Bass program was adopted by the California Fish and Game Commission in February 1993 under the Black Bass Conservation and Management Act of 1980. Trinity, Oroville, Clear, Isabella, and Castaic lakes are designated as trophy black bass waters.

The addition of slot limits to catch and release requirements are another potential option for reducing human exposure to species with high methylmercury levels. There are already many catch and release requirements for specific locations and species.

<u>Other options</u>. Other more speculative options for controlling bioaccumulation include:

- Lime additions to increase pH and water hardness to reduce bioaccumulation, as well as reduce methylation (see Chapter 4 and section 7.3.4). This factor could be reassessed in the future via a literature review.
- Selenium additions to reduce methylmercury bioaccumulation (Mailman et al. 2006). Although selenium is simple to apply and is inexpensive, there are inconsistencies in the known interactions between selenium and methylmercury, and selenium has a narrow concentration range before there are risks of aquatic toxicity. Consequently, staff does not recommend this option for attempting to reduce fish methylmercury concentrations.

7.4.5 Predictions for Improvement Based on Fisheries Management

Earlier sections identified staff predictions of where different types of reservoir fisheries management practices might measurably reduce fish methylmercury or otherwise reduce exposure to fish with elevated methylmercury levels. Table 7.1 identifies our predictions for each reservoir and describes any additional assumptions made. As illustrated by the Table 7.1 predictions, fish methylmercury reductions due to fisheries management practices may be possible in about two-thirds of the reservoirs.

Many potential management practices described in previous sections have been employed elsewhere in the world but not in California, or if in California, not for the specific purpose of reducing reservoir fish methylmercury concentrations. In addition, the predictions are based on limited data sets and could change based on additional monitoring data and completion of pilot tests for California reservoirs.

Even so, the predictions, combined with the conceptual model findings and linkage analysis, indicate additional pilot tests and associated studies are warranted. Further, reservoir fisheries management practices have the potential to not only make measurable improvements in many reservoirs, but also to do so relatively quickly (e.g., <10 years).

Consequently, staff recommends that parties responsible for fisheries management of mercury-impaired reservoirs complete individual or coordinated pilot tests of different fisheries management practices. The purpose of the pilot tests would be to develop effective and economically feasible technologies and management practices to reduce reservoir fish methylmercury concentrations. The fisheries responsible parties should coordinate and collaborate amongst themselves and with entities that manage reservoirs. After the pilot tests and associated studies are completed, they can be evaluated using an adaptive implementation approach to determine which reservoirs in California are amenable to different management practices.

7.4.6 Recommendations

Based on considerations and evaluations outlined in previous sections and chapters, staff recommends that responsible parties for fisheries management of mercury-impaired reservoirs complete individual or coordinated pilot tests of different fisheries management practices. The purpose of pilot tests would be to develop effective and economically feasible technologies and management practices to reduce reservoir fish methylmercury concentrations. Test results would be incorporated in the Reservoirs Mercury Control Program using an adaptive implementation approach.

Staff does not recommend selenium addition or bass eradication as options for reducing methylmercury bioaccumulation and exposure.

7.5 Need for Reservoir-Specific Strategies

This section identifies a variety of factors that need to be considered to develop strategies to ensure the proposed fish methylmercury targets are attained in every reservoir included in the Reservoir Mercury Control Program. The large number of factors that control mercury methylation and bioaccumulation complicates resolving the mercury impairment in California. However, the large number of factors also increases the number of possible tools that may be available to reduce reservoir methylmercury levels. Accordingly, there should be a possible solution to mercury impairment for every reservoir, no matter how unique the reservoir. Due to the interrelated nature of factors controlling methylation and bioaccumulation, care must be taken to account for competing factors and reservoir-specific conditions prior to undertaking control actions.

7.5.1 Competing Factors and Other Considerations

<u>Competing factors</u>. There are many competing factors that control methylmercury production and bioaccumulation. For example, increased primary production may *decrease* fish methylmercury levels through algal bloom dilution and somatic growth dilution. Conversely, increased primary production may *increase* fish methylmercury because increased primary production may mean higher aqueous methylmercury concentrations due to increased turbidity, which decreases light penetration and which in turn decreases photodemethylation. Or, higher aqueous methylmercury concentrations may be the result of greater anoxia upon algal decay. Accordingly, an evaluation of possible competing factors should be undertaken in the course of pilot tests.

<u>Reservoir factors.</u> We anticipate that operational requirements and mandates may not allow for all methylmercury management tools to be used in all reservoirs. There are many different types of reservoirs in California due to the state's highly varied topography and climate, as well as different reservoir uses (e.g., power production, flood control, supply, and water level stabilization). In addition, the reservoir type may be further delineated by spatial, physical, and chemical characteristics (e.g., elevation, depth, annual precipitation, geology, upstream inputs, amount of water level fluctuations or drawdown, and water residence time). A combination of these characteristics may lead to operational constraints as well as lend to the uniqueness of some reservoirs, which could limit the use of some methylmercury management tools.

Consequently, the type of reservoir can greatly affect the mercury cycling that occurs, and the designed use of the reservoir will be a major factor in controlling the water quality parameters that affect mercury cycling. For instance, reservoirs designed to stabilize water level fluctuations will have less methylation from drying and rewetting of sediments in comparison to flood control reservoirs that require large drawdown for flood water storage. Run-of-the-river reservoirs and other small reservoirs that regulate flow from larger reservoirs will likely have comparatively shorter residence times and consequently less methylation (due to factors such as less warming so lower bacterial metabolism, increased reservoir mixing, and reduced strength of stratification and anoxia). Reservoirs designed for power production may require a larger head of water resulting in overall deeper reservoir designs; deep reservoirs have a greater tendency to thermally stratify and thus produce methylmercury in the hypolimnion than do shallow reservoirs.

<u>Watershed factors</u>. Conditions upstream of a reservoir affect conditions within a reservoir. Reservoirs with multiple upstream impoundments will be comparatively different from those without upstream impoundments. Specifically, reservoirs with upstream impoundments will have reduced inputs of sediment and sediment-associated pollutants and nutrients, decreased productivity (i.e., cultural oligotrophication, see section 4.3.2 and Appendix A), increased dry season inflows, and maybe reduced storm flows. This combination of factors may increase fish methylmercury levels. Yet, these same upstream conditions provide continued inflow during warm summer months, which may increase reservoir mixing and may reduce the strength and duration of stratification and degree of anoxia; this in turn may reduce methylmercury production and consequently may decrease fish methylmercury levels.

Consequently, mercury control actions will likely vary by type of reservoir and some may be reservoir-specific due to competing factors. This emphasizes the need for an adaptive implementation approach that includes additional pilot tests and associated studies to determine the most effective way to achieve the proposed targets in every reservoir. This also highlights the need for reservoir-specific mercury management strategies.

7.5.2 Long-Term Management Strategies

As illustrated by Table 7.1, staff does not expect that each of the controllable processes outlined in previous sections of this chapter will be controllable in every mercury-impaired reservoir. Many factors influence methylmercury levels in reservoir fish. Some factors affect mercury sources and methylation, some factors affect mercury bioaccumulation, and a few factors affect both. Some factors are synergistic while others are competing. Further, not all factors are controllable for each reservoir.

Mercury reduction actions will likely need to vary for each reservoir or type of reservoir. This is due to a variety of factors, such as: different combinations of mercury sources (some are natural or global and therefore not regulated by state and federal agencies); different applicability of mercury prey fish and CA least tern objectives; if either prey fish or CA least tern objectives are more stringent than sport fish objective, then it may require more effort and longer time to achieve these objectives; competing factors that control methylmercury production; and distinct operational constraints.

Consequently, although staff encourages coordinated pilot tests for representative reservoirs, after tests and studies are completed, parties responsible for reservoir operations and fisheries management will need to submit a long-term reservoir management strategy to the Water Board in addition to a final report on the pilot tests. The long-term reservoir management strategy should identify actions that will be taken to ensure the proposed methylmercury fish targets are achieved in each reservoir included in the Reservoir Mercury Control Program.

7.6 Considerations for Future Reservoir Construction and Maintenance

7.6.1 New Reservoir Construction

Mailman and others (2006) summarized possible methylmercury mitigation actions for new hydroelectric reservoirs, which included the following: site selection to reduce potential mercury impacts; intensive fishing; selenium, lime, or phosphorus additions; controlled burn before flooding; removal of standing trees before flooding; increased photodemethylation; capping or dredging of bottom sediments; aeration; and water level management. They concluded the most promising strategies were site selection, intensive fishing, and selenium additions. However, they did not consider several known strategies including source reduction (e.g., cleanup of mine sites before inundating with water) and some new strategies such as minimal nitrate addition that emerged subsequent to their publication.

The following strategies could be particularly effective for new reservoirs in California:

- Select reservoir sites in watersheds that have (a) few or no historical mercury, gold, or silver mines, and (b) few or no mercury mineralized zones or other naturally mercury enriched areas.
- Conduct controlled burns or other vegetation removal activities before flooding.
- If a reservoir site is in a watershed with historical mine sites, (a) remediate actively eroding mine sites and downstream mining waste upstream of the site, and (b) conduct comprehensive soil mercury monitoring of area to be inundated and cap or remove contaminated soils before flooding.
- Do not stock high trophic level species such as brown trout and bass.

Many of these concepts also apply to managing reservoirs during extended drawdown, such as vegetation and contaminated soils removal along exposed shorelines. Once a reservoir is flooded, the options reviewed in earlier sections of this chapter for reservoir and fisheries management may also be applicable.

Operations plans for new reservoirs should include management plans and activities to prevent or reduce methylmercury production and ongoing monitoring to assess the effectiveness of the control actions.

7.6.2 Reservoir Maintenance

Most dams are constructed to collect water, but they also collect sediment. Minear and Kondolf (2009) determined reservoir sedimentation is a serious problem in many California regions with high sediment yield, and small-capacity reservoirs in rapidly eroding mountain regions are most vulnerable to sedimentation problems. Their analysis indicated that sedimentation rates are small relative to overall storage capacity in California reservoirs, but some individual reservoirs have been affected because of their small capacities and high sediment yields of their catchments.

Reservoir maintenance includes dredging accumulated sediment to maintain water storage capacity and for other reasons, some described in the following example from Lake Combie. The Nevada Irrigation District is sponsoring a mercury removal pilot test at Lake Combie that is expected to demonstrate how water management and mineral resource extraction efforts can coordinate to:

- Restore and maintain Lake Combie’s water storage capacity;
- Improve recreational opportunities and boat access within Lake Combie; and
- Extract marketable gravel, sand and clay by dredging sediment from the reservoir and using multiple recovery processes to remove elemental mercury from the sediment.

Dredging is expected to remove mercury-contaminated sediment and reduce the amount (mass) of elemental mercury in the reservoir. The mercury recovery processes being developed by the Nevada Irrigation District are needed to comply with Clean Water Act requirements to ensure discharges to the reservoir from dredging and extraction activities are not elevated in mercury compared to ambient water levels. In addition, the mercury recovery processes are expected to enable a broader market for the extracted materials.

There may be additional benefits of the dredging. As stated in the Lake Combie pilot test description, “Dredging may also make the northeastern end of the reservoir that is currently shallow and warm and therefore likely conducive to methylation less conducive, because dredging will create deeper and cooler conditions. In this way the project is expected to reduce not only the source material for methylmercury (elemental mercury in the sediment) but will also change the conditions in which the methylation process currently takes place” (NID 2009). Nevada Irrigation District is partnering with the U.S. Geological Survey to measure the effects of removing elemental mercury and reducing methylation conditions by conducting environmental monitoring before, during, and after the dredging and mercury removal operations.

The pilot test is estimated to take between three to five years and $6 million to $8 million to complete (NID 2009; Locke 2009). If this project demonstrates that mercury can be effectively removed from reservoir sediments and pilot test discharges to the reservoir, the process has the potential to be applied periodically. Maintenance dredging to maintain reservoir capacity is estimated to reoccur on 10-year intervals at Lake Combie. This process also has the potential to be applied at other reservoirs throughout the Sierra Nevada, which could improve water storage capacity, potentially help address methylmercury impairments in those reservoirs, and potentially help reduce the amount of inorganic mercury and methylmercury transported to downstream mercury-impaired rivers and estuaries. More recent information on the mercury removal project at Lake Combie is available on the Nevada Irrigation District mercury removal project website[5] and The Sierra Fund’s “Get the Mercury Out Campaign” website.[6]

Lake Combie is one of many California reservoirs located in rapidly eroding regions that are contaminated by mercury from legacy gold mines. (The high density of gold mines in reservoir watersheds in the Sierra Nevada is illustrated on Figures 6.6B and 6.7A.) Hence, storm flows will continue to transport mercury-contaminated sediment into Lake Combie and similar reservoirs, and reservoir sediment mercury concentrations (compared to mercury mass) are not expected to decrease until the upstream mine sites and creeks are remediated. Remediating upstream mine sites might be a more effective method to reduce reservoir sediment mercury concentrations, and in some cases sedimentation amounts. However, reservoirs located far downstream of one or more mine sites will likely have a long lag time before benefits from remediation (lower sedimentation and mercury concentrations) are realized. Mine site remediation prioritization considers this lag time (see section 7.2.1).

Dredging activities and return water from dredging activities have the potential to discharge sediment (and associated sediment-bound and dissolved mercury and other constituents of concern) into the water column. Accordingly, dredging projects should employ BMPs during and after dredging and excavation activities to minimize such discharges. BMPs are already required by Water Board-issued permits (i.e., Waste Discharge Requirements and CWA Section

[5] http://nidwater.com/conservation/mercury-removal-project/

[6] http://www.sierrafund.org/projects/get-mercury-out/

401 Certifications) for these types of projects to ensure they meet water quality objectives for turbidity and other Clean Water Act requirements. Actions to minimize sediment and associated sediment-bound mercury releases into the water column could include, but are not limited, to the following:

- Use a pipeline hydraulic suction dredge or "sealed" or "environmental" clamshell bucket dredge to reduce the amount of turbidity in the water column and the amount of water produced during the dredging operation; and/or
- Increase dredge material disposal pond return water hold time to remove suspended material from the return flow to the maximum extent practicable.

Monitoring of return waters for turbidity, mercury, and other constituents of concern should be conducted to demonstrate that the BMPs employed to reduce constituents of concern are adequate to meet permit requirements.

Re-use or disposal of dredged materials in upland sites has the potential to discharge sediment (and associated sediment-bound mercury) if the dredged materials are not protected from stormwater erosion. Accordingly, placement of dredged material at upland sites should employ BMPs during and after dredging and excavation activities to minimize erosion. BMPs are already required by Water Board-issued permits (i.e., Waste Discharge Requirements and CWA Section 401 Certifications) for these types of projects to ensure they meet water quality objectives for turbidity. Actions to minimize erosion could include, but are not limited, to the following:

- Construct surface water diversion channels and sub-drains to route clean surface water runoff away from placement site;
- Place dredged materials in stable configuration (i.e., proper de-watering, compaction, and terraced slopes);
- Plant (re-vegetate) exposed dredge materials with native vegetation to minimize sheet-flow erosion at the placement site; and
- Construct and maintain stormwater retention basins, swales, or other engineered features designed to slow surface runoff, reduce surface erosion, and eliminate sediment runoff from the placement site.

It might be appropriate to study some reservoir dredging projects to determine if they are effective in reducing methylation of mercury. These studies could include before-and-after sampling, such as the following:

- Mercury sampling of surface sediments and small fish; and
- Water sampling for methylation conditions that could change as a result of deepening, e.g., depth profiles of temperature, dissolved oxygen, and redox potential.

7.7 Consequences of no Reservoir Mercury Control Program

This section describes why, if California were not to have a program to control mercury in reservoirs, the problem of elevated fish methylmercury levels would likely worsen.

7.7.1 Cultural oligotrophication and other reservoir creation effects

Likely consequences of no program to control mercury in reservoirs are increases in fish methylmercury levels in reservoirs downstream of other reservoirs due to cultural oligotrophication. As described in Chapter 4 and Appendix A, decreased productivity (i.e., cultural oligotrophication) may be causing or contributing to the mercury impairment of many reservoirs. The vast majority of reservoirs in California are likely beyond the influence of the "new" reservoir flooding spike in methylation, and they continue to enhance methylmercury production and bioaccumulation. The proposed Reservoir Mercury Control Program includes actions to reduce inorganic mercury sources and manage in-reservoir methylmercury production and bioaccumulation, which could control cultural oligotrophication and in reservoirs newly-created in the future could control "new" reservoir flooding spike in methylation.

7.7.2 Global Industrial Emissions

Likely consequences of no program to control mercury in reservoirs are increases in fish methylmercury levels due to methylation of mercury from global industrial emissions. Although California cannot regulate these mercury emissions, the proposed Reservoir Mercury Control Program includes actions to manage in-reservoir methylmercury production and bioaccumulation, which could control methylation of this source of mercury. This is further described in the following paragraphs.

As noted in previous sections and chapters, mercury emissions are deposited directly on the relatively large water surface of reservoirs. This is important because the mercury deposition to reservoir water surfaces is more quickly incorporated into the food web than mercury from other sources.

Global anthropogenic emissions are the primary anthropogenic source to 17 of the 74 (>20%) 303(d)-listed reservoirs. If global emissions are not soon reduced, fish methylmercury reduction strategies for these reservoirs will need to focus entirely on in-reservoir water chemistry and fisheries management practices to achieve the proposed sport fish target.

Further, reservoirs and other waters throughout California could experience increasing fish methylmercury concentrations if global industrial emissions increase, particularly those where global industrial emissions are the primary anthropogenic source (see Table 6.17). The "status quo" AMAP emission scenario indicates global emissions may increase by about 20% by 2020 (see Chapter 6 and Appendix H). California clearly is dependent upon other states and countries to reduce emissions to achieve the load allocation for global anthropogenic emissions. USEPA and other states' regulations are expected to continue to greatly reduce U.S. anthropogenic contributions to the global atmospheric pool of mercury.

Admittedly, there is uncertainty about when and whether anthropogenic emission sources outside of the United States will be reduced or will continue to increase, particularly sources related to economic development in Asia. As noted in section 7.2.2, future changes in global mercury emissions are dependent on several variables, including development of national and regional economies, development and implementation of technologies for reducing emissions, possible regulatory changes, and global climate change. Global rules and treaties are needed to ensure global emissions will not increase, much less to accomplish substantial emission reductions.

Finally, recent global biogeochemical modelling efforts indicate significant reductions in mercury emissions will be necessary just to stabilize current levels in the global environment (Amos et al. 2013). Amos and others (2013) predict that future atmospheric deposition will increase even if current anthropogenic emissions are held constant because of the interactions and cycling lag times between the atmosphere, land, and oceans. Their model indicates most mercury emitted to the air ends up in the oceans within a few decades, where it can then remain or cycle between the ocean surface and atmosphere for centuries to millennia before ultimately being sequestered in the deep ocean. For example, they found that half of mercury pollution in the present ocean surface comes from anthropogenic emissions prior to 1950, and they predict that future mercury burdens in the oceans and associated atmospheric deposition will increase as anthropogenic emissions after 1950 end up in the oceans. Amos and others (2013) conclude that aggressive global mercury emission reductions will be necessary just to maintain oceanic mercury concentrations and atmospheric deposition rates at present levels.

These findings indicate that mercury impairments in California reservoirs associated with global industrial emissions will remain, and likely worsen, if no additional actions are taken. Further, California may need to rely entirely on in-reservoir water chemistry and fisheries management practices to achieve the proposed sport fish target, much less achieve the target in a timely manner, where global industrial emissions are the primary anthropogenic source to mercury-impaired reservoirs.

7.7.3 Anthropogenic Mercury Stored in Watershed Soils

Likely consequences of no program to control mercury in reservoirs are increases in fish methylmercury levels due to elevated levels of mercury in landscape soils and the natural processes of soil erosion and stormwater transport to reservoirs. Although it is not feasible to restore landscape soils to pre-industrial natural background mercury levels, the proposed Reservoir Mercury Control Program includes actions to manage in-reservoir methylmercury production and bioaccumulation, which could control the effects of this source of mercury.

Even if all local and global industrial emissions were immediately reduced to zero, substantial fish methylmercury reductions may take a long time to occur. Most of the mercury deposited to land by atmospheric deposition—70% to 99%—is stored in the soils and vegetation and released gradually over time (see Chapter 6). Consequently, it could take decades to centuries for industrial-era mercury in watershed soils and channel sediments to be depleted.

Fish methylmercury levels could decline in approximately a decade in those reservoirs that receive most of their mercury from direct deposition (Harris et al. 2007). Such reservoirs have a relatively large surface to watershed area ratio and no point sources.

However, for reservoirs with small surface areas compared to their watershed areas and no point sources, there may be some initial decline in fish methylmercury as a result of reduced direct deposition. Subsequent declines could take decades to centuries in response to the depletion of industrial-era mercury stored in watershed soils (Golden and Knightes 2008; Harris et al. 2007; Perry et al. 2005; Lorey and Driscoll 1999; Mason et al. 1994).

Consequently, California may need to rely on in-reservoir water chemistry and fisheries management practices to achieve the proposed fish methylmercury targets in a timely manner, and maintain them over the long term, where reservoir impairments are associated primarily with atmospheric deposition and they have small surface areas compared to their to watershed areas.

7.7.4 Mining Waste in Upstream River Channels and Floodplains

Likely consequences of no program to control mercury in reservoirs are continued elevated fish methylmercury levels due to continued inputs of mercury from historical mining. Although it is not feasible to remediate all mercury-contaminated mining wastes quickly, the proposed Reservoir Mercury Control Program includes recommendations for how to prioritize remediation. This particular prioritization likely would not occur without a program to control mercury in reservoirs.

Reservoirs in mining regions are still impaired even though more than a century has passed since historical gold and mercury mining operations ceased. This indicates that we cannot expect reservoir mercury impairments caused by historical mining activities to be resolved quickly (i.e., in a few decades). Millions of kilograms of mercury entered California’s waterways from mercury and gold mining operations in the 1800’s and early 1900’s and much of this occurred upstream of reservoirs. Stabilization of mining waste at mine sites and in downstream channel banks and floodplains and other remediation actions at mine sites would be effective at preventing additional mine-related mercury from entering California’s waterways.

7.7.5 Global Climate Change

Likely consequences of no program to control mercury in reservoirs are increases in fish methylmercury levels due to methylation of mercury from global industrial emissions. Although global climate change is highly unlikely to be reversed, the proposed Reservoir Mercury Control Program includes actions to manage in-reservoir methylmercury production and bioaccumulation, which could control the effects of global climate change. This is further described in the following paragraphs.

The source assessment, linkage analysis, methylmercury allocation, and total mercury reduction requirements described in this report are based on present climate conditions. However, present and past conditions may no longer be a reliable guide to the future due to global climate change (DWR 2008a).

Global climate change refers to observed changes in weather features that occur across the earth as a whole, such as temperature, wind patterns, precipitation, and storms, over a long period (CAT 2006; CEC 2006a; CEC 2008; IPCC 2007). Earth has a dynamic climate that is evidenced by repeated episodes of warming and cooling in the geologic record. Consistent with a general warming trend, global surface temperatures have increased by 0.74°C ± 0.18°C over the past 100 years (IPCC 2007). During the same period, sea level rose 7 inches along

California's coast, average temperature in the state rose 1°F, and average spring snowpack in the Sierra Nevada decreased by about 10% (DWR 2008a).

The recent warming trend has been correlated with the Industrial Revolution, which resulted in increased urban and agricultural centers at the expense of forests and reliance on fossil fuels (CAT 2006). Although natural processes and sources of greenhouse gases contribute to warming periods, recent warming trends are attributed to human activities as well (CAT 2006; CEC 2006a).

Climate change models have predicted several scenarios for global, national, and local changes that could affect California's reservoirs. Warmer temperatures; reduced water abundance and quality; changes in precipitation patterns such as more winter flooding but less annual precipitation; and changes in frequency and intensity of weather events are just some of the changes that could impact reservoirs and their water supply, habitats, and biota (Cayan et al. 2012; CAT 2006; CEC 2006a and 2008; TRNA 2009; Brekke et al. 2004; Knowles and Cayan 2002; Miller et al. 2003; Service 2004; Stewart et al. 2004). Impacts to specific reservoirs will be affected by the rate of warming and potential precipitation changes within their respective drainage basins. Examples of predicted changes and effects include the following:

- The Sierra Nevada snow pack, California's largest surface "reservoir," has been decreasing each year and further reductions are expected (CAT 2006; CAPCOA 2009; DWR 2008b; TRNA 2009; Conrad 2013). Models project the Sierra Nevada snowpack will decrease by 25% to 40% by 2050, which would decrease streamflow inputs to reservoirs (DWR 2008b).
- Warmer temperatures may increase evaporation and evapotranspiration rates and extend growing seasons, which would require more water (CAPCOA 2009).
- Drier years could result in more frequent and intense wildfires (CAPCOA 2009; CAT 2006; CEC 2006a and 2006c).
- Changes in rainfall and runoff patterns combined with warmer temperatures are expected to change the intensity, frequency, and timing of flood events (CAPCOA 2009).
- High frequency flood events will most likely increase, changing watershed vegetation and erosion patterns (CAPCOA 2009; CEC 2006a and 2008).
- Increases in flooding and wildfires would increase sedimentation rates, which would likely negatively affect reservoir capacity, wildlife habitat and fisheries, and water quality (DWR 2008b).
- Changes in water quality could include higher water temperatures, lower dissolved oxygen, higher turbidity, and concentrated pulses of pollutants, all of which could stress fish, increase growth of algae, and cause hypoxia in surface water bodies (DWR 2008b; TRNA 2009; USEPA 2012d).
- Traditional water management practices and timing of water availability, which are based on natural climate variability, may change due to both increased warming and increased variability in streamflow amounts and timing (Milly et al. 2008; Hirsch et al. 2011; Vicuna and Dracup 2007; USEPA 2012d).

- Sea level rise is already occurring; the exact rate is unknown but it is correlated to the melting rate of the ice sheets on the western Antarctica and Greenland, and could result in abrupt changes in sea level conditions (CAT, 2006; CEC, 2006b). Sea level rise could result in increased salt water intrusion in the Delta and other estuaries, which could affect the timing and amount of upstream reservoir releases to manage intrusions (CEC, 2006a, 2006d, and 2008; TRNA, 2009).

The net results of climate change may have unpredictable consequences on ecological processes in California's reservoirs including the production and bioaccumulation of methylmercury. As noted in section 7.5.1, there are many competing factors that control methylmercury production and bioaccumulation. Similarly, the effects of climate change are expected to have varied and even competing consequences for mercury inputs to and methylation and bioaccumulation within California's reservoirs. Potential effects include but are not limited to the following:

- Warmer inflow water temperatures could reduce seasonal thermal stratification. Reductions in thermal stratification could reduce in-reservoir methylmercury production. However, it could also lead to overall increases in reservoir water temperatures, which could have confounding effects on fish methylmercury concentrations.
    - Warmer water temperatures could increase primary production, which may *decrease* fish methylmercury levels through algal bloom dilution and somatic growth dilution.
    - Or conversely, warmer water temperatures could *increase* fish methylmercury because increased primary production may mean higher aqueous methylmercury concentrations due to increased turbidity, which decreases light penetration and which in turn decreases photodemethylation.
    - Increased primary production also could result in decreased dissolved oxygen because decomposition of (more) algae requires (more) oxygen. Less dissolved oxygen could in turn lead to increases in in-reservoir methylmercury production and aqueous and fish methylmercury concentrations.
    - Further, increased primary production also could result in increased organic matter in sediment as a result of (more) decaying algae settling on the reservoir bottom. Increased organic matter in sediment can enhance methylmercury production by providing a food source to sulfate-reducing bacteria; however, organic matter also can reduce the potential for methylation and bioaccumulation by decreasing the bioavailability of mercury to biota due to complex binding (see Chapter 4 for more review).
- Increases in the frequency, scale, and intensity of flooding and wildland fires are likely to increase the amount of watershed erosion, and consequently the amount of mining waste and sequestered mercury in watershed soils from long-term industrial emissions transported to reservoirs (Krabbenhoft and Sunderland. 2013; Amos et al. 2013). This has the potential of increasing reservoir sediment mercury concentrations, which in turn could increase fish methylmercury concentrations.
- Increases in the frequency, scale, and intensity of flooding, along with runoff occurring earlier in the year, are likely to lead to operational changes to manage seasonal water

inflows for planned and contracted water releases and deliveries. Operational changes could have a variety of confounding effects on fish methylmercury concentration.

- Warmer water temperatures and changes in other reservoir water chemistry traits could alter food supply and types of fish and other biota that reside in reservoirs. For example, high-methylmercury predatory species such as bass could become more prevalent.

A recent literature review by Krabbenhoft and Sunderland (2013) found that many studies have suggested that climate change will exacerbate methylmercury production and bioaccumulation in aquatic ecosystems, but more information is needed to improve understanding of specific impacts to California reservoirs.

These findings indicate that reservoir mercury impairments will remain, and likely worsen, if no additional actions are taken.

In addition, these findings highlight the need for reservoir-specific methylmercury management strategies discussed in section 7.5 to account for potential changes to reservoir characteristics and operations. Further, staff recommends an adaptive implementation approach that includes re-evaluation of the allocations and linkage relationships associated with changing environmental conditions as part of periodic program reviews.

7.8 Minimal Adverse Consequences from Implementation Recommendations

This section explores the possibility of inadvertent adverse consequences of implementing recommendations for the Reservoir Mercury Control Program outlined in this chapter. These topics and more will be addressed in two future companion documents, the *CEQA Evaluation for Statewide Mercury Program*, and the *Economic Evaluation for Statewide Mercury Program* (see Chapter 1).

The program initially entails (a) reductions in sources of inorganic mercury, (b) pilot tests of management practices for reservoir water chemistry and fisheries, and (c) incorporation of an adaptive approach to implementation. Accordingly, active management of reservoir water chemistry and fisheries (i.e., full-scale implementation) would not occur until a later date. This section explores the possibility of inadvertent adverse consequences of implementing the program, even if the program fails to ultimately achieve the proposed sport fish target.

7.8.1 Inorganic Mercury Source Control

Source control is a basic requirement to solve pollution problems, as recognized by the TMDL equation: load allocations plus waste load allocations plus a margin of safety equals loading capacity. The proposed total mercury source reduction requirements are based on actions previously undertaken elsewhere, and so are achievable. Some source reduction actions may have short-term adverse environmental consequences, and will be considered in the future companion document, *CEQA Evaluation for Statewide Mercury Program* (see Chapter 1).

For example, mine site remediation will likely require grading and excavation. Such heavy equipment operations have the potential to degrade wildlife habitat during construction. These operations may even temporarily eliminate wildlife habitat not only during construction but for months afterward until vegetation has re-established. Some of these adverse consequences cannot be avoided or fully mitigated, despite using best construction management practices. Yet, mine site remediation to reduce discharges of pollutants is required with or without this Reservoir Mercury Control Program, per the Porter-Cologne Water Quality Control Act. Similarly, it is expected that upgrades of wastewater treatment plants will be required for reasons other than mercury discharges. Therefore, there are minimal additional adverse consequences from the proposed total mercury source reduction requirements.

Additionally, the proposed source reductions recognize that mercury is a naturally occurring element plentiful in California, and that it is not possible to achieve natural background soil mercury concentrations in all reservoirs in the next couple of decades or even for centuries. Further, the proposed source reductions recognize that discharges that make negligible contributions to reservoir mercury should not have to undertake costly actions that result in no perceptible reductions in reservoir mercury levels, and hence no perceptible environmental benefit. The proposed source reduction requirements are focused on the most important sources and do not include blanket requirements for all sources. This helps minimize inadvertent adverse consequences.

Furthermore, source control will reduce total mercury present in the upstream waters between the discharge point and the downstream reservoir. These reductions also are anticipated to reduce the production of methylmercury in these upstream waters. Hence, this program likely has the unintended benefit of improving the quality of some upstream waters, and reducing methylmercury in reservoir inflows.

7.8.2 Limiting Factors

The proposed source reductions and allocations are based on total mercury not being the only limiting factor in fish methylmercury—rather, that methylation and bioaccumulation are also limiting factors (see Chapters 4 and 5). If later it is determined that total mercury is the dominant factor in fish methylmercury, then greater reductions would have been necessary for total mercury sources (e.g., beyond currently known or anticipated technologies). This finding would be discovered through adaptive implementation and program review.

However, staff recommendations call for individual or coordinated pilot tests of methods to reduce in-reservoir methylmercury production and bioaccumulation. The purpose of the pilot tests would be to develop effective and economically feasible technologies and management practices to reduce reservoir fish methylmercury concentrations. However, the weight of evidence provided in the peer-reviewed literature, in addition to the linkage analysis in Chapter 5, indicates that methylation and bioaccumulation are indeed important factors.

7.8.3 Reservoir Water Chemistry and Fisheries Management

Moreover, staff recommendations recognize that source control alone will not achieve the proposed sport fish target in all reservoirs. The linkage analysis (Chapter 5) and source assessment (Chapter 6) findings indicate that even if we were to eliminate all anthropogenic source inputs, there would still be impaired reservoirs. Therefore, we recommend pilot tests of reservoir water chemistry and fisheries management practices that are likely to reduce fish methylmercury levels.

To avoid unwarranted duplication of effort, and for efficiency, staff recommends pilot tests be conducted in a few, representative reservoirs. Testing only a few reservoirs may be advantageous in the event that any management practices prove to be ineffective or have unacceptable adverse environmental consequences. Previous studies showed that minimal nutrient addition to reservoirs has a transient effect, such that within a few years nutrients added to reservoirs are exported or bound permanently in bottom sediments. In other words, the reservoirs revert to their previous water quality condition. However, if it turns out that these previous studies are not relevant to California, and nutrient addition permanently increases nutrients, then the studies also should document the unintended negative consequences of nutrient additions.

For an example of a management practice that may prove to be ineffective, a recent study in Washington's Twin Lakes showed that oxygenation for fisheries increased zooplankton methylmercury levels. This oxygenation occurred higher in the water column, and not at the sediment-water interface (Dent et. al. 2014). This could have the adverse consequence of increasing fish methylmercury levels.

However, it is unlikely the pilot tests will cause unacceptable adverse environmental consequences. This is because these management practices have been tested elsewhere so there are some guidelines available to prevent harm, and because their effects are likely to be fully reversed in a relatively short time after the tests are stopped. Therefore, there are minimal adverse consequences from the proposed pilot test requirements. Furthermore, the pilot tests would enable the identification of where different reservoir water chemistry and fisheries management practices can feasibly take place, i.e., where they are and are not compatible with reservoir operations.

7.8.4 Methylmercury Source Control

Staff recommends watershed methylmercury source reductions not be required in the first phase. (As mentioned above, some reduction in methylmercury in reservoir inflows is anticipated from total mercury source reductions.) However, watershed methylmercury source reductions may be needed in the future to achieve the proposed sport fish target in every reservoir. Accordingly, we recommend that the implementation plan include a program review with pre-established guiding questions. Some of the guiding questions should be: "Is it necessary to reduce sources of methylmercury as well as inorganic mercury to attain the sport fish target? If so, what methylmercury sources require reduction, and how and where might implementation actions be effective?" Program review should involve a literature review of current, relevant scientific literature, and evaluation of monitoring data generated by this program. A coordinated approach for monitoring of methylmercury in reservoir inflows is also recommended.

The first program review may conclude that there is insufficient data to immediately direct watershed methylmercury source reductions. In this event, additional studies would be needed, and there would be further delay before methylmercury source reductions could be directed.

Although such delay is undesirable, the phased approach herein of first addressing total mercury sources and testing reservoir water chemistry and fisheries management practices is supported by the scientific literature (Conceptual Model in Chapter 4) and linkage analysis (Chapter 5). Both of these chapters describe that both methylmercury produced within the reservoir and in-reservoir total mercury are strongly correlated with fish methylmercury levels. Therefore, there are minimal adverse consequences resulting from postponing watershed methylmercury source reduction to later phases of the program.

In any event, implementation of staff recommendations herein would likely reduce fish methylmercury levels in many reservoirs. This is a beneficial outcome for California, even if the sport fish target cannot be achieved quickly. In conclusion, there are minimal adverse environmental consequences expected from staff recommendations for the statewide Reservoir Mercury Control Program.

8 ALLOCATIONS, TMDL, AND LOADING CAPACITY

This chapter presents several proposed Total Maximum Daily Load (TMDL) elements that apply to mercury-impaired reservoirs (see section 1.5) and supports Mercury Reservoirs Provisions Chapters IV.C.2. and IV.C.3. (Chapter 2 also presents proposed TMDL elements, namely the TMDL targets.) This chapter presents waste load allocations (WLAs) for point sources of mercury to reservoirs, load allocations (LAs) for non-point sources of mercury to reservoirs, a load allocation (LA) for in-reservoir methylmercury production, and establishes the mercury TMDL and loading capacity for reservoirs. Detailed rationale and calculations are in Chapter 7.

The source allocations are calculated in a way that enables them to be applied to both current and future reservoirs identified as impaired by mercury. Initially, the allocations apply to current sources to the 74 reservoirs impaired by mercury (Table 1.1). The allocations apply to currently identified and any new point and nonpoint sources in the watersheds upstream of the 74 reservoirs as well as to atmospheric deposition originating from local and global anthropogenic and natural emissions.

Sections 8.1 and 8.2 describe the mercury TMDL, loading capacity, and LAs and WLAs. Table 8.1 summarizes the allocations. Table 8.2 provides the allocations for specific National Pollutant Discharge Elimination System (NPDES)-permitted point sources. Tables 8.3 and 8.4 list wastewater and storm water NPDES-permitted point sources considered to be negligible and therefore not assigned a WLA. Section 8.3 describes how the allocations incorporate a margin of safety to address uncertainty and interannual and seasonal variability. In view of the proposed LAs and WLAs, section 8.4 describes the attainability of beneficial use protections, narrative and numeric water quality objectives, and antidegradation policies.

8.1 TMDL and Loading Capacity

TMDLs are "[t]he sum of the individual [*waste load allocations*] for point sources and [*load allocations*] for nonpoint sources and natural background" (40 CFR § 130.2[i]). Accordingly, the mercury TMDL for reservoirs is the combination of (a) inorganic mercury WLAs for large and small NPDES-permitted discharges from municipal and industrial facilities; (b) inorganic mercury LAs for mining waste, soils, and atmospheric deposition; and (c) methylmercury LA for reservoir water. The LAs for soils and atmospheric deposition include natural background sources. These allocations are provided on Table 8.1.

Loading (assimilative) capacity is "[t]he greatest amount of loading that a water can receive without violating water quality standards" (40 CFR § 130.2[f]). Accordingly, the mercury loading capacity for reservoirs is the mercury TMDL for reservoirs.

8.2 Load and Waste Load Allocations

Water Board staff recommends establishing a concentration-based TMDL with concentration-based allocations for all sources except atmospheric deposition because, as described in the linkage analysis (Chapter 5), methylmercury levels in fish are linked to sediment and water mercury concentrations. In addition, as discussed in Chapters 6 and 7, a concentration-based approach also better enables us to evaluate the feasibility of source reductions for many of the sources, and similarly, compliance monitoring is easier and less expensive.

Allocations are divided among LAs for nonpoint sources and WLAs for point sources. LAs apply to mining waste, soils, atmospheric deposition, and in-reservoir methylmercury production, while WLAs apply to discharges from existing and future NPDES-permitted facilities.

LAs for most nonpoint sources are in the form of total mercury concentrations of *suspended sediments* (i.e., particulate mercury) in their runoff because mercury from these sources is strongly associated with suspended sediment. In contrast, WLAs are in the form of total mercury concentrations in facility effluent discharges because discharges from most NPDES-permitted facilities tend to be very low in suspended solids. LAs for atmospheric deposition are in the form of annual mass deposited onto California.

8.2.1 Load Allocations for Mining Waste and Soils

LAs for mining waste and soils apply to runoff from: (a) non-mine areas (non-urbanized upland areas), (b) mercury mine sites, (c) gold and other mine sites where mercury was used, and (d) mining waste downstream of mine sites. These LAs apply to runoff directly to or upstream of mercury-impaired reservoirs. This section provides descriptions of these allocations by mercury region, whereas in Table 8.1 these allocations are grouped by mine effects, i.e., by non-mine areas, mine sites, and mining waste downstream of mine sites. The goal for these LAs is to reduce to the extent feasible inputs of mercury to mercury-impaired reservoirs caused by anthropogenic activities to restore beneficial uses. This goal is consistent with the Clean Water Act requirement that "the TMDL and associated waste load and load allocations must be set at levels necessary to result in attainment of all applicable water quality standards… 40 CFR130.7(c)(1)."

Mine sites and areas with mining waste may be subject to anthropogenic erosion from historical mining activities that denuded landscapes and led to mass wasting, gullying, and surface erosion. In addition, these sites are subject to further anthropogenic erosion from modern activities including but not limited to managing timber lands; grazing and other agricultural practices; road construction and maintenance; and other construction activities. Storm water, dust control, and irrigation runoff transports erodible or eroded materials to reservoirs. Anthropogenic erosion is controllable, whereas controlling natural erosion across the State is not feasible. "Erodible" means material readily available for transport by storm water and irrigation runoff to surface waters.

These LAs are based on the mercury regions described in the source assessment (Chapter 6), as follows: mercury-mineralized zones, mercury-enriched areas, and trace mercury areas. The mercury region of a particular mining waste discharge can be determined by (a) proximity to a historical mercury mine, (b) presence of geologic formations known or suspected to have elevated mercury concentrations (e.g., surface presence of Franciscan or Stony Creek geologic formations particularly near fault zones), or (c) site-specific monitoring of background soils and rock formations.

The LAs for the three mercury regions are described in the bullets below. The mining waste definition referred to is from California Water Code section 13050 (q)(1): "all solid, semisolid, and liquid waste materials from the extraction, beneficiation, and processing of ores and minerals. Mining waste includes, but is not limited to, soil, waste rock, and overburden, as defined in Section 2732 of the Public Resources Code, and tailings, slag, and other processed waste materials…" Mining waste may be located at or near mine sites, including ore excavation and processing areas, and roads or property near mine sites that contain mining waste. Mining waste discharges include, but are not limited to, storm water runoff from ore piles, contaminated soil under processing sites, processing facilities and equipment, and other process areas and equipment impacted by mine operations and exposed to storm water such that mercury may be transported to surface waters.

- The LA for runoff from mercury-mineralized zones is 400 mg/kg (dry weight, annual median). This mercury concentration is characteristic of background levels observed at mercury mine sites in the Coast Ranges. This allocation applies to anthropogenic erosion and discharge of soils from mercury-mineralized zones and to discharges of mining waste as defined above from mercury mines.
- The LA for runoff from mercury-enriched areas is 0.3 mg/kg (dry weight, annual median). This is the modern background mercury concentration in soils in mercury-enriched areas. This allocation applies to anthropogenic erosion and discharge of soils from mercury-enriched areas and to discharges of mining waste as defined above from non-mercury mines. This allocation applies to areas downstream of mercury mines but outside of mercury-mineralized zones into which mercury mining waste has been transported.
- The LA for runoff from trace mercury areas is 0.1 mg/kg (dry weight, annual median). This is the modern background mercury concentration in soils in trace mercury areas. This allocation applies to anthropogenic erosion and discharge of soils from trace mercury areas and to discharges of mining waste as defined above from non-mercury mines.

Allocations for mining waste and soils are for total mercury concentration in suspended sediment, i.e., particulate mercury. Soil fines on the landscape become suspended sediments, i.e., mercury-contaminated particles, when they are transported by runoff to surface waters. Concentration of mercury in suspended sediment is calculated as the ratio of aqueous concentrations of mercury to suspended sediment (Hg/TSS or Hg/SSC). Units for the concentration of mercury in suspended sediment are part per million (ppm; equivalent to ng/mg or mg/kg). Mercury concentrations on suspended sediment are best characterized by the median concentration.

It is possible to translate these suspended sediment allocations to measurements of mercury in surface soil using the following concepts. Fines are the silt and clay portion of soil that is less than 63 microns in diameter and is readily suspended in the water column, reported as mg/kg or ppm, dry weight. Hence, measurements of mercury in erodible surface soil fines are considered comparable to measurements to suspended sediment. Measurements of mercury in erodible soil fines are averaged yearly during the dry season.

The LAs for mining waste and soils will be implemented as management practices and will not be assigned as cleanup standards or numeric effluent limitations. Cleanup standards will be established as necessary and appropriate, typically on a site-specific basis and based on a risk evaluation that identifies the most sensitive receptor, whether on-site or downstream.

8.2.2 Load Allocations for Atmospheric Deposition

The total mercury LAs for atmospheric deposition are as follows:

- 1,400 kg/yr for deposition from natural sources;
- 230 kg/yr for deposition from anthropogenic sources within California; and
- 1,600 kg/yr for deposition from anthropogenic sources outside of California.

The allocations apply to the annual load of total mercury deposited in California by atmospheric wet and dry deposition. The allocations include mercury deposited to inland water surfaces (e.g., creeks, rivers, lakes, and reservoirs) and to land surfaces (e.g., urban areas within and outside of Municipal Separate Storm Sewer Systems [MS4s], forests, agricultural areas, undeveloped areas, and mine sites).

The LA for deposition from natural sources is equal to the existing load calculated using USEPA's Regional Modeling System for Aerosols and Deposition (REMSAD) model output for 2001 and literature values (see Chapter 6). This LA applies to deposition attributed to geologic deposits, volcanoes, volatilization from the ocean, and other natural sources that cannot be controlled.

The LAs for deposition attributed to anthropogenic sources within and outside of California incorporate reductions of 66% and 50%, respectively, compared to USEPA's REMSAD model output for 2001 atmospheric deposition. As reviewed in more detail in Chapter 7, these reductions account for improvements in emission controls since 2001, inter-annual variability due to economic factors, and substantial emission reductions from recent and anticipated local, state, federal, and global rules and treaties.

8.2.3 Load Allocations for In-Reservoir Methylmercury Production

The LA for in-reservoir methylmercury production applies to methylmercury production within mercury-impaired reservoirs. The LA for methylmercury in reservoir water is no detectable methylmercury in unfiltered reservoir water (calendar year median for the entire water column, including the epilimnion and hypolimnion) with a detection limit not exceeding 0.009 ng/L. The allocation is based on the achievable detection limit as described in USEPA method 1630 documentation (see Chapter 5).

The goal for this allocation is to operate engineered and managed reservoirs so that reservoir fish attain mercury water quality objectives by minimizing the transformation of mercury to methylmercury. This goal is consistent with the Federal Clean Water Act requirement that "the TMDL and associated waste load and load allocations must be set at levels necessary to result in attainment of all applicable water quality standards… 40CFR [§]130.7(c)(1)."

8.2.4 Waste Load Allocations for NPDES-Permitted Discharges from Municipal and Industrial Facilities

WLAs apply to facilities with individual NPDES permits that discharge directly to or upstream of mercury-impaired reservoirs. These facilities are categorized as large, small, or negligible dischargers based on their design flows. As described in section 6.6.2 of the source assessment (Chapter 6), facility design flow is an adequate surrogate for total mercury load to determine whether facilities make significant mercury contributions to mercury-impaired reservoirs.

WLAs are assigned to large and small dischargers, but not to negligible dischargers. The WLA category is determined by comparing the sum of design annual and dry weather flows for NPDES-permitted facility discharges to or upstream of a mercury-impaired reservoir to the annual and dry weather reservoir inflows, respectively. Figure 8.1 provides a flow chart that describes how facilities are categorized as large, small, or negligible dischargers, and the applicable WLA. Table 8.2 provides the WLAs specific to facilities that discharge directly to or upstream of mercury-impaired reservoirs on the 2010 303(d) List. (Table 8.2 will be expanded to include facilities that discharge directly to or upstream of the “next set” of impaired reservoirs (see Chapter 1) prior to circulating the staff report for public review) The WLAs are the 95th or 99th percentile of recent, pooled statewide facility effluent total mercury concentration data (see Chapter 6).

Large dischargers are dischargers with individual NPDES permits that have design discharge flows greater than one million gallons per day (>1 MGD) <u>and</u> the sum of the NPDES-permitted facility discharges directly to or upstream of a mercury-impaired reservoir exceeds 1% of the reservoir annual inflow or exceeds 1% of the reservoir dry weather inflow. The allocation for large municipal wastewater treatment plants (WWTPs) and facilities where no discharge flow data is available is 10 ng/L, and for all other types of facilities is 30 ng/L.

Small dischargers are dischargers with individual NPDES permits that have either (a) design discharge flows greater than 0.2 MGD but equal to or less than 1 MGD, or (b) design flows >1 MGD but the sum of the NPDES-permitted facility discharges to or upstream of a reservoir does not exceed 1% of the reservoir annual inflow and does not exceed 1% of the reservoir dry weather inflow. The allocation for small municipal WWTPs is 20 ng/L, and for all other types of facilities is 60 ng/L.

Negligible dischargers are dischargers with individual NPDES permits that have design discharge flows equal to or less than 0.2 MGD. In addition, as explained in section 6.6 of the source assessment (Chapter 6) and Appendix E, discharges subject to State and Regional Water Board general NPDES permits are negligible discharges of mercury to reservoirs. Negligible dischargers are not assigned a WLA and can discharge without a WLA or corresponding permit numeric effluent limitation (NEL) for mercury. Table 8.3 identifies the individual and general NPDES permits for negligible discharges directly to or upstream of mercury-impaired reservoirs on the 2010 303(d) List. (Table 8.3 will be expanded to include facilities with negligible discharges directly to or upstream of the “next set” of impaired reservoirs (see Chapter 1) prior to circulating the staff report for public review .)

WLAs apply to the 12-month average effluent total mercury concentration calculated each calendar year at the end of December. WLAs apply to the total effluent of a waste discharge at the end-of-pipe, except in rare situations where it is impractical or infeasible (e.g., where the final discharge point is inaccessible or the pollutants are so diluted by cooling water as to make monitoring impractical). For facilities such as hydro-power plants and fish hatcheries that make use of surface water intakes from the same water bodies as their discharge receiving waters, the WLAs apply to the mercury discharges from internal waste streams, not to once-through cooling water discharges or other discharges of ambient surface water. The Water Board will apply intake credits to once-through cooling water and other discharges as allowed by law. (See section 1.4 Calculation of Effluent Limitations (subsection D) and section 1.4 Intake Water Credits in the State Water Board's 2005 *Policy for Implementation of Toxics Standards for Inland Surface Waters, Enclosed Bays, and Estuaries of California*.)

If a discharger has more than one outfall to a given mercury-impaired reservoir's watershed, the WLA category (large or small) is determined by the sum of all its outfall flows in that reservoir watershed. The WLA applies to the average of total mercury concentrations measured for all its outfalls in a given calendar year in that watershed.

The WLAs should be implemented as NELs in the NPDES permits. The NELs should be expressed as calendar year average total mercury effluent concentrations and should be included in NPDES permits when they are reissued, and in any new NPDES permits when they are issued.

Note that a more stringent NEL may apply to facility discharges to a tributary to a mercury-impaired reservoir to protect beneficial uses of the receiving water. For example, if a facility discharges to a 303(d)-listed mercury-impaired creek or river upstream of a mercury-impaired reservoir, a more stringent NEL or WLA may apply in the future when TMDLs are developed for the upstream impaired rivers and creeks.

8.2.5 Expanded and New Facility Discharges

The WLAs apply to discharges from new facilities, and new or expanded discharges from existing facilities, with individual NPDES permits and design flows greater than 0.2 MGD that discharge directly to or upstream of any mercury-impaired reservoir. Expanded facility discharges and discharges from new facilities should have WLAs assigned based on the same rationale illustrated in Figure 8.1. The WLAs should be implemented as NELs in the NPDES permits. The NELs should be expressed as calendar year average total mercury effluent concentrations and included in NPDES permits when they are issued.

The WLA can be applied to new discharges in both current and future mercury-impaired reservoir watersheds for two reasons. First, the WLAs were calculated based on data available from all California facilities, not only those upstream of mercury-impaired reservoirs on the 2010 303(d) List. Second, although the WLA categories are based on facility design flows, the WLAs themselves are concentration-based, and therefore are not flow-dependent.

The WLAs account for future growth in existing and new discharges because the WLA categories are based on design flows rather than current flows, and because they are based on the sum of design flows in a watershed. The WLAs accommodate facility expansion up to their currently-permitted facility design flow. If future expansions or other new discharges cause the watershed sum of annual or dry weather design flows to exceed 1% of reservoir inflows, then all the facilities in that reservoir watershed that discharge greater than 1 MGD can be re-evaluated using the methodology described in Figure 8.1.

8.2.6 NPDES-Permitted Urban Runoff

NPDES-permitted urban runoff discharged by Municipal Separate Storm Sewer Systems (MS4s) and by construction and industrial activities is considered a point source. However, a WLA specific to urban runoff is not needed for two reasons. First, the atmospheric deposition source of mercury to urban runoff is accounted for in the LAs for atmospheric deposition. Atmospheric deposition from local and global emissions is the primary source of mercury to urban runoff, as explained in Chapter 6. Mercury in urban runoff from atmospheric deposition is accounted for in the LAs for atmospheric deposition in Table 8.1 and will be addressed through the controls on atmospheric emission sources that are required to meet the LAs. Table 8.4 identifies the individual and general NPDES permits for storm water and other urban runoff that are addressed by the LAs for atmospheric deposition. The LAs for atmospheric deposition address deposition to existing and future urban, industrial, and other developed areas.

Second, the contribution of mercury to urban runoff from local use and improper disposal of mercury-containing products is expected to decrease to almost zero by the implementation of recent statewide mercury reduction rules. The many bans on new mercury use in California and the implementation of institutional controls and best management practices are expected to reduce this urban source of mercury to insignificant amounts (see Chapters 6 and 7). Consequently, a WLA is not assigned to this discharge.

8.3 Margin of Safety

This section provides the margin of safety and presents the following related analyses: seasonal variations and critical conditions, and daily load expressions.

8.3.1 Margin of Safety

TMDL analyses must incorporate a margin of safety to address potential uncertainties. The margin of safety is intended to account for any lack of knowledge concerning the relationship between load and WLAs and water quality. The margin of safety can be derived either explicitly or implicitly. Providing an implicit margin of safety involves using conservative assumptions (more likely to be over-protective than under-protective) throughout the analysis. Alternatively, an explicit margin of safety involves reserving a specific mercury LA for the margin of safety. This TMDL incorporates an implicit margin of safety.

Staff recommended mercury allocations for watershed and global sources. However, the linkage analysis in Chapter 5 indicates that source control alone is insufficient to attain the sport fish target in all mercury-impaired reservoirs. As a result, staff also recommended a methylmercury allocation of non-detect for reservoir water. In addition, Chapter 7 identifies potential fisheries management practices to reduce methylmercury bioaccumulation in the reservoir food web. The combination of allocations assigned to in-reservoir (watershed and global) sources as well as fisheries management provide redundancy and hence an implicit margin of safety.

The proposed sport fish target provides a small and implicit margin of safety for wildlife. Whereas wildlife consume whole fish, this target will be monitored in fillet samples so that human exposure can be evaluated. The fillet is the muscle portion of fish where highest levels of methylmercury typically bioaccumulate. Therefore, use of fillet samples from fish that are of legal size provides a small margin of safety for wildlife that eat whole fish. Similarly, there is a small margin of safety when a fish eaten by an animal is smaller than legal size. Only some fish species are subject to legal size restrictions, so this extra protection is estimated to be minor.

Additionally, a conservative approach was employed in the standardized fish data in the linkage analysis (Chapter 5 and Appendix B). Reservoir-specific fish methylmercury concentrations standardized for length and species were used in the linkage analysis, rather than *average* methylmercury concentrations. The sport fish target (*average* methylmercury concentration of 0.2 mg/kg in legal-sized TL4 fish) is virtually the same concentration of methylmercury in standardized fish (see Figure 5.2). This comparison is conservative because the sport fish target applies to all TL4 species, whereas the standardized fish data are dominated by bass. Bass typically have higher methylmercury concentrations than more commonly consumed TL4 species such as catfish.

8.3.2 Seasonal Variations and Critical Conditions

Federal regulations and USEPA guidance direct TMDLs to consider seasonal variations and critical conditions. Many of the factors affecting critical conditions for mercury exhibit seasonal variations. Staff considered seasonal and inter-annual variations in inorganic mercury loads and concentrations and the critical condition of anoxia needed for methylmercury production in the development of this TMDL.

Seasonal and Inter-annual Variability in Mercury Loads and Concentrations

Staff considered the substantial inter-annual variability in the amount of precipitation reservoir watersheds receive, resulting in fluctuation in the amount of sediment and water delivered to reservoirs among years. Increases or decreases in the volume of water or mass of sediment delivered could alter the amount of mercury delivered to reservoirs from one year to the next.

Similarly, staff considered seasonal variability in total mercury loads to and concentrations in reservoirs. Essentially, in the wet season, total mercury is transported in storm water, whereas methylation and bioaccumulation largely occur in the dry season when and where the critical condition of low oxygen (anoxic conditions) occurs. The allocations proposed in this chapter are intended to address seasonal variations and critical conditions.

Seasonal and inter-annual variability is accounted for because the TMDL targets are set to concentrations of methylmercury in fish, and fish tissue concentrations necessarily integrate reservoir conditions over time.

Critical Condition of Anoxia

As described in the Conceptual Model (Chapter 4), nearly all California reservoirs thermally stratify during the summer months. During thermal stratification, the hypolimnion becomes anoxic. The anoxic hypolimnion creates conditions more favorable for sulfate reducing bacteria metabolism and subsequent methylmercury production and build-up. This has resulted in significantly higher methylmercury concentrations in the hypolimnion of reservoirs than in the epilimnion. During fall overturn, the built-up methylmercury in the hypolimnion can be entrained into the epilimnion and accumulated into the food web.

The proposed Implementation Plan (Chapter 9) addresses this critical condition of elevated methylmercury production by recommending that coordinated studies and pilot tests evaluate methods to reduce methylmercury production during the critical period of anoxia.

8.3.3 Expression of Daily Load

A TMDL need not be stated as a daily load (40 CFR § 130.2[i]). Other measures besides a daily load are allowed if appropriate.

Loading (assimilative) capacity is "[t]he greatest amount of loading that a water can receive without violating water quality standards" (40 CFR §130.2[f]). TMDLs are "[t]he sum of the individual waste load allocations for point sources and load allocations for nonpoint sources and natural background.… TMDLs can be expressed in terms of either mass per time, toxicity, or other appropriate measure" (40 CFR §130.2[i]).

For this TMDL, a daily TMDL is inappropriate for the allocations and TMDL due to (1) the temporal component embedded in the objectives or targets that the allocations were developed to protect, and (2) the nature of mercury transport to and methylmercury production in reservoirs.

Allocations established on an annual basis are better suited to the goal of protecting human health and wildlife beneficial uses related to consuming reservoir fish. The mercury water quality objectives and TMDL numeric targets to protect these uses are in the form of fish tissue methylmercury. Fish tissue methylmercury targets reflect environmental exposure over months to years; in other words, exposure is integrated over time, and therefore it is preferable to express the TMDL as an annual average rather than in daily time steps to ensure attainment of the targets. Consequently, the allocations are intended to represent long-term averages and account for long-term variability in mercury transport to and methylmercury production in reservoirs. Therefore, the allocations are established on an annual, rather than daily, basis.

8.4 Water Quality Standards Attainment

The Clean Water Act requires that a TMDL and associated LAs and WLAs be set at levels that attain all applicable water quality standards, which include beneficial use protections, narrative water quality objectives, numeric water quality objectives, and antidegradation policies (see Chapter 1 for details). As described in Chapters 5 and 7, due to the complexity of mercury cycling in reservoirs, it is not possible to rely solely on mercury source controls via LAs and

WLAs to achieve the sport fish target in each reservoir. Therefore, this TMDL proposes a combination of feasible LAs and WLAs for mercury sources, stringent LA for methylmercury production, and both water chemistry and fisheries management. Actions to reduce fish methylmercury levels likely will need to vary for each reservoir because of the many combinations of different mercury sources (e.g., some are natural or global and therefore not regulated by state and federal agencies), competing factors that control methylmercury production, and reservoir operational constraints. Further, the Implementation Plan (Chapter 9, particularly "Assessing Progress in Reducing Fish Methylmercury Levels" in section 9.8) utilizes an adaptive implementation approach to ensure all applicable targets will be measured and met.

8.4.1 Beneficial Uses

Of the many beneficial uses of reservoirs, only the following are impaired by mercury:

- Human consumption of fish: Commercial and Sport Fishing (COMM)
- Wildlife consumption of fish: Wildlife Habitat (WILD), and preservation of Rare and Endangered Species (RARE)

One or two TMDL numeric targets apply to each mercury-impaired reservoir (see Figure 2.1). Although not all of these beneficial uses apply to every reservoir, the targets are exactly equal to the statewide mercury water quality objectives and were selected to attain all of the applicable beneficial uses. Attaining all of the TMDL numeric targets applicable to each mercury-impaired reservoir will attain the beneficial uses of COMM, WILD, and RARE applicable to each reservoir.

8.4.2 Narrative Water Quality Objectives

Narrative water quality objectives for bioaccumulation are included in three Regional Water Board Basin Plans, as follows:

- San Francisco Bay Region (Region 2): Many pollutants can accumulate on particles, in sediment, or bioaccumulate in fish and other aquatic organisms. Controllable water quality factors will not cause a detrimental increase in concentrations of toxic substances found in bottom sediments or aquatic life. Effects on aquatic organisms, wildlife, and human health will be considered.
- Los Angeles Region (Region 4): Many pollutants can bioaccumulate in fish and other aquatic organisms at levels which are harmful for both the organisms as well as organisms that prey upon these species (including humans). Toxic pollutants will not be present at levels that will bioaccumulate in aquatic life to levels which are harmful to aquatic life or human health.
- Santa Ana Region (Region 8): Toxic substances shall not be discharged at levels that will bioaccumulate in aquatic resources to levels which are harmful to human health. The concentrations of toxic substances in the water column, sediments or biota shall not adversely affect beneficial uses.

While these narrative water quality objectives apply to any pollutant that can bioaccumulate in aquatic organisms, they will be met for mercury by attaining the TMDL numeric targets. The targets are equal to the statewide mercury objectives and provide a numeric interpretation of the three Basin Plan narrative objectives for bioaccumulation, and are protective of wildlife and human health.

8.4.3 Numeric Water Quality Objectives

The USEPA has established California Toxics Rule (CTR) criteria of 50 and 51 ng/L total recoverable mercury for freshwater sources of drinking water from waters designated with and without the MUN beneficial use, respectively . Regional Water Boards have also established total mercury water column objectives of 25; 200; 2,400; and 10,000 ng/L. The San Francisco Bay Water Board established a 25 ng/L objective and this Board plans to vacate it for reservoirs (and other waters) when the statewide mercury water quality objectives are established. The rest of this section provides a summary of objective exceedances of 50 ng/L and higher.

These numeric objectives are already met in all samples from most California reservoirs. (Data discussed herein is provided in Appendix Z, Table Z.3.) These objectives are met most of the time even in reservoirs adjacent to the Sulphur Bank and New Almaden mercury mines—reservoirs known to have severe mercury contamination and therefore already addressed by mercury TMDLs and excepted from this statewide program. The maximum total mercury concentration in Clear Lake (Sulphur Bank) was 400 ng/L, and one sample from Guadalupe Reservoir (New Almaden) exceeded 50 ng/L. The rest of this section discusses data from mercury-impaired reservoirs listed on Table 1.1.

Several water samples from Lake Nacimiento have exceeded 200 ng/L, and 11 of 29 samples have exceeded 50 ng/l. However, only one tributary to Lake Nacimiento is affected by abandoned mercury mines. Consequently, elevated mercury concentrations in Lake Nacimiento are localized to the area downstream of Las Tablas Creek (Gilbane 2015). USEPA superfund is addressing the Klau and Buena Vista mercury mine sites on Las Tablas Creek. The remediation of these mine sites is expected to reduce mercury concentrations in Las Tablas Creek, and also in Lake Nacimiento.

Mercury in some water samples has exceeded 50 ng/L in 4 reservoirs to which the Statewide Mercury Control Program for Reservoirs is applicable. Infrequent exceedances of 50 ng/L occurred in Lake Mendocino and Lake Pillsbury—just 1 and 2 of more than 30 samples. The CTR criteria are for 30-day average concentrations. Given the low frequency of exceedance, it is unlikely that these reservoirs exceed the CTR criteria.

For example, in Lake Sonoma 6 of 34 samples have exceeded 50 ng/L. Lake Sonoma has mercury mines located in its watershed , and remediation of these mine sites is expected to reduce mercury concentrations in Lake Sonoma.

The exceedances of 50 ng/L in Lake Mendocino and Lake Pillsbury are very infrequent—just 1 and 2 of more than 30 samples. The CTR criteria are for 30-day average concentrations. Given the low frequency of exceedance, it is unlikely that these reservoirs exceed the CTR criteria.

The Central Coast Regional Water Board has established an aquatic organism body burden total mercury objective of 500 mg/kg wet weight. However, the TMDL targets are for a more toxic form of mercury, namely, methylmercury. Additionally, the TMDL targets are many orders of magnitude lower than the Central Coast Region's objective and are more protective of wildlife and human health. Therefore, attaining the TMDL numeric targets will attain the Central Coast Region's aquatic organism objective.

The San Francisco Bay and Central Valley (Regions 2 and 5) have also established site-specific TMDL targets and water quality objectives for mercury or methylmercury in fish tissue. Reservoirs to which these TMDLs apply are excepted from this Reservoir Mercury Control Plan (see section 1.4).

8.4.4 Antidegradation Policies

The Statewide Mercury Control Program for Reservoirs complies with both federal and state antidegradation policies because it is designed to attain the TMDL targets (and hence the mercury water quality objectives), which in turn will restore the beneficial uses and ensure high water quality. Specifically, both USEPA and the State Water Board have antidegradation policies. The federal policy (40 CFR § 131.12) requires that water quality standards be set at levels that protect beneficial uses. The State Water Board's "Statement of Policy with Respect to Maintaining High Quality of Water in California" (Antidegradation Implementation Policy; Resolution No. 68-16) requires that waste discharges not cause pollution or nuisance and ensure high water quality.

In summary, the Statewide Mercury Control Program for Reservoirs complies with the Clean Water Act requirement to attain all applicable water quality standards.

9 IMPLEMENTATION PLAN

This chapter presents the strategy ("implementation plan") to achieve the goals of the Statewide Mercury Control Program for Reservoirs, which are the following:

1. Reduce fish methylmercury concentrations in reservoirs that have already been determined to be mercury-impaired;
2. Have a control program in place that will apply to additional reservoirs when they are determined in the future to be mercury-impaired; and
3. Protect additional reservoirs from becoming mercury-impaired.

Organization of this chapter

This chapter contains the implementation plan to achieve the goals of the Statewide Mercury Control Program for Reservoirs, describes the Water Board's regulatory authority to compel actions, specifies implementation actions and parties responsible for these actions, and provides an overview of monitoring and reporting. The implementation plan is presented in the following sections:

Chapter 9 organization and the corresponding Mercury Reservoir Provisions

The implementation actions in the Mercury Reservoir Provisions (which utilize Roman numeral “chapter” references) correspond to the organization of this chapter (which utilize Arabic numeral “section” references) as follows:

III. Implementation Program for Non-Impaired Reservoirs or Non-Assessed Reservoirs

- III.A. Discharges from Dredge and Fill Activities
  - 9.10 Dredging, Use, and Disposal of Mercury-Contaminated Sediments In or Upstream of Reservoirs (“Discharges from Dredge and Fill Activities”)

IV. Implementation Program for Impaired Reservoirs

- IV.D. Discharges from Mine Sites
  - 9.2 Mine Sites Upstream of Mercury-Impaired Reservoirs
- IV.E. Discharges from Dredge and Fill Activities
  - 9.10 Dredging, Use, and Disposal of Mercury-Contaminated Sediments In or Upstream of Reservoirs (“Discharges from Dredge and Fill Activities”)
- IV.F. Reservoir Owners and Operators
  - 9.8 Reservoir Water Chemistry Management Actions for Mercury-Impaired Reservoirs;
  - 9.9 Fisheries Management Actions for Mercury-Impaired Reservoirs; and
  - 9.11 New Reservoirs
- IV.G. Municipal and Industrial Wastewater Non-Stormwater NPDES Dischargers
  - 9.7 Municipal and Industrial Wastewater Facility Discharges to Mercury-Impaired Reservoirs (“Non-Stormwater NPDES Dischargers”)
- IV.H. Storm Water NPDES Dischargers
  - 9.5 Urban Runoff to Mercury-Impaired Reservoirs (“Storm Water NPDES Dischargers”)

V. Recommendations

- V.A. Outreach Activities Regarding Fish Consumption Advisories
  - 9.12 Exposure Reduction Activities to Protect Human Health
- V.B. Fisheries Management
  - 9.9 Fisheries Management Actions for Mercury-Impaired Reservoirs; and
  - 9.12 Exposure Reduction Activities to Protect Human Health
- V.C. Reductions in Atmospheric Mercury
  - 9.4 Atmospheric Deposition

VI. Program Review: State Water Board Reconsideration of Mercury Reservoir Provisions

- 9.13 Adaptive Management and Program Review

9.1 Overview of Implementation Plan

The Water Boards recognize that reservoirs are vital to California and that reservoir operations face challenges from floods, droughts, and climate change. Especially in response to challenges posed by climate change, reservoir operators will likely need to nimbly manage water chemistry that could change from year-to-year. Therefore, this mercury program addresses controllable water quality factors and does not impose any restrictions on water supply.

In the first decade, reservoir owners and operators would test feasible reservoir management actions. The Water Boards encourage a coordinated approach for fewer, focused tests rather than tests in all mercury-impaired reservoirs. The test results will be evaluated by an independent, third-party Technical Review Committee before the Water Boards would develop long term requirements for all mercury-impaired reservoirs.

While the reservoir testing program is underway, the Water Boards will ensure that mercury sources are controlled to all mercury-impaired reservoirs.

Achieve all applicable targets

One or two TMDL targets are applicable to each mercury-impaired reservoir. (These TMDL targets correspond to the one or two mercury water quality objectives applicable to each reservoir, see Chapter 2.) This implementation plan is designed to achieve all applicable targets in mercury-impaired reservoirs.

In accordance with the Mercury Reservoir Provisions, for impaired reservoirs for which two targets apply, both targets must be achieved—even if the mercury impairment determination was based on one target.

Monitoring to demonstrate achievement of all applicable targets is described in Chapter 10. Monitoring to assess progress in reducing fish methylmercury levels is described in section 9.8.6.

Phases and program review

Implementation actions to achieve all applicable targets would occur over two phases. Phase 1 consists of mercury source controls (see next section) and pilot tests in a subset of impaired reservoirs. Reservoirs that are part of hydropower projects licensed by the Federal Energy Regulatory Commission are excluded from mercury pilot test requirements in Phase 1. Phase 1 is expected to last for 10 years, after which the State Water Board would conduct a program review of the Mercury Reservoirs Provisions and evaluate the results of the pilot tests. The State Water Board program review would identify effective and feasible reservoir management actions based on results of the reservoir pilot tests (described below) and would develop Phase 2 implementation actions. See section 9.13 for a discussion of program review.

Phase 2 would not begin until after the State Water Board completes its program review of Phase I and adopts an amendment to the Mercury Reservoir Provisions contained in the Water Quality Control Plan for Inland Surface Waters, Enclosed Bays, and Estuaries of California. The Mercury Reservoir Provisions direct that program review will encompass consideration of whether, in Phase 2, implementation actions would apply to reservoirs (and corresponding mercury sources) determined by the State Water Board to be mercury-impaired subsequent to the Board's adoption of the Mercury Reservoir Provisions. Procedures to identify impaired reservoirs and their watershed mercury sources are provided in the last section of Chapter 1. The Mercury Reservoir Provisions (Chapter VI.B.) also provide that the Board's program review will include consideration of whether to impose mercury control implementation requirements in Phase 2 on hydroelectric projects licensed by FERC located at impaired reservoirs.

Reservoirs and mercury control actions

Table 9.1 is a preliminary list of Phase 1 mercury-impaired reservoirs and Federal Energy Regulatory Commission (FERC) hydropower licenses (see Chapter 1 regarding plans to finalize this list subsequent to scientific peer review). The mercury control actions in this implementation plan apply to different sets of reservoirs and are presented in the following sections:

- Mercury source control actions for dredging and studies needed for atmospheric deposition apply statewide and are described in sections 9.10 and 9.4, respectively.
- Recommendations for exposure reduction for all reservoirs, and which are particularly needed for impaired reservoirs, are provided in section 9.12.
- Mercury source control actions that apply to mercury sources upstream of impaired reservoirs are described in sections 9.2–9.3, and 9.5–9.7.
- Reservoir water chemistry and fisheries management pilot tests apply to a subset of Phase 1 impaired reservoirs, namely non-FERC-licensed impaired reservoirs; the pilot tests are described in sections 9.8 and 9.9.
- Mercury source and methylation control actions for new reservoirs are described in section 9.11.

Chapter 1 (in section 1.8; and Mercury Reservoir Provisions in Chapter V.I.) describes that after the completion of Phase 1, the State Water Board will hold a public hearing pertaining to the issues it will consider during its Program Review. During program review, the State Water Board would determine if reservoirs should be placed into different mercury impairment categories (i.e., determine which reservoirs are still impaired or newly determined to be impaired). Also during program review, the State Water Board could decide if there will be a set list of impaired reservoirs for the duration of Phase 2, or if the list will be revised periodically.

In addition, during program review the State Water Board could determine whether and when to require additional pilot tests, i.e., pilot tests in reservoirs newly determined to be impaired. Additional pilot tests, rather than proceeding directly to full-scale implementation for some reservoirs, might be needed for different reasons. For example, to resolve operational issues for an expensive best management practice proven in pilot tests for other reservoirs, by conducting a pilot test in a localized portion of a reservoir newly determined to be impaired. Another example would be to use a site-specific pilot test to scale up a best management practice for full-scale implementation. Favorably, if pilot tests are needed after Phase 1, the duration and cost of pilot tests are expected to decrease with each successive wave of mercury-impaired reservoirs incorporated into the Statewide Mercury Control Program for Reservoirs.

Effective date

After the State Water Board adopts the Mercury Reservoir Provisions, the Mercury Reservoir Provisions are effective upon approval by the California Office of Administrative Law.

Waters excluded from the program and TMDL

The Statewide Mercury Control Program for Reservoirs does not apply to the waters listed on Table 1.2. Mercury control programs (TMDLs) were previously approved for these waters. In the future, the applicable Regional Water Board may revise or modify the mercury control programs listed on Table 1.2 (in accordance with Wat. Code, §§ 13240 –13247). Additionally, the applicable Regional Water Board may rescind or vacate mercury control programs listed on Table 1.2. After rescinding or vacating, at some future time and after consideration by the State Water Board, the Statewide Mercury Control Program for Reservoirs may become applicable to these waters if they are impaired reservoirs.

9.1.1 Key Actions in Phase 1

Reservoirs: pilot tests

Owners and operators of mercury-impaired reservoirs (see Table 9.1) would conduct pilot tests of methods to reduce methylmercury concentrations in reservoir fish. FERC-licensed reservoirs would be excluded from mercury pilot test requirements in Phase 1. Owners and operators could coordinate the development of pilot tests such that the tests are conducted in fewer, targeted reservoirs rather than each of the owner's or operator's reservoir. Reservoir owners and operators would convene a third-party independent Technical Review Committee to advise on pilot tests.

Reservoir owners and operators would use lessons learned from pilot tests to develop long-term reservoir and fisheries management plans. The Technical Review Committee and the Water Boards would evaluate results of pilot tests and proposed long-term reservoir and fisheries management plans.

Potential pilot tests

Potential management actions that could be pilot tested are either directed at (a) water chemistry to reduce methylmercury production, or (b) fisheries to reduce fish bioaccumulation of methylmercury.

Potential water chemistry pilot tests are the following:

(1) Oxidant addition to reservoir bottom waters (near the sediment-water interface) to reduce anoxia or adjust redox potential when reservoirs are stratified to suppress methylation of mercury. Evaluate various oxidants (e.g., dissolved oxygen, ozone, nitrate, others) for (a) efficacy for methylmercury reduction, (b) multiple benefits (e.g., drinking water quality, algal controls), and (c) avoidance of adverse consequences;

(2) In-reservoir sediment removal or encapsulation to address inorganic mercury hotspots such as submerged or near-shore mine sites and mining waste; and

(3) Other management practices to reduce methylation, including enhancing demethylation.

Potential fisheries pilot tests are the following:

(1) Nutrient management such as minimal additions of nitrogen or phosphorus (including from natural sources such as restoring historical salmon runs) to slightly increase chlorophyll-a concentrations in oligotrophic reservoirs;

(2) Intensive fishing to increase the growth rate of remaining fish;

(3) New or changes to fish stocking practices to increase the abundance of fish with lower methylmercury levels, such as (a) stock low-methylmercury prey fish for reservoir predator fish to consume, (b) stock more or different sport fish species, such as lower trophic level sport fish, and/or (c) stock large, old predator fish from hatcheries that supply low methylmercury fish; and

(4) Assess potential changes to make to fish assemblage that result in top predator fish with lower methylmercury levels.

Mine sites upstream of reservoirs

The Water Boards would compel, using existing authorities, cleanup of the highest priority mine sites upstream of mercury-impaired reservoirs. Cleanup of highest priority mine sites is expected to reasonably quickly decrease reservoir mercury concentrations.

Exposure reduction

Human health should be protected while pilot tests are underway and inorganic mercury source reductions are occurring. This would involve reservoir owners and operators, the State Department of Public Health, Office of Environmental Health Hazard Assessment, California Department of Fish and Wildlife, and other stakeholders, for actions such as the following:

(1) Post fish consumption warning signs;

(2) Recommend fish catch restrictions to reduce human consumption of larger, older fish with high methylmercury levels, e.g., “slot limits” that specify a safer size range of fish for consumption; and

(3) Conduct public outreach and educational activities to discourage people from consuming fish with highly elevated methylmercury.

Atmospheric deposition

The California Air Resources Board and USEPA should evaluate atmospheric deposition of mercury to California. California already reduced anthropogenic emissions of mercury by more than half since 2001 and is expected to achieve the proposed load allocation by the end of Phase 1. The Water Boards would encourage USEPA to increase its efforts to address mercury emissions from foreign countries (particularly artisanal gold mining on several continents and power plant emissions in Asia).

9.1.2 Other Actions in Phase 1

Urban runoff to Mercury-Impaired Reservoirs (Storm water NPDES Dischargers)

"MS4 permittees" are responsible for urban runoff from municipal separate storm sewer systems (MS4s) regulated by National Pollutant Discharge Elimination System (NPDES) permits. Certain MS4 entities would monitor methylmercury in their discharges upstream of or directly to mercury-impaired reservoirs. This requirement applies to highly urbanized areas that comprise a substantial amount of the reservoir watershed. In program review after Phase 1, the Water Boards would evaluate these data as a first step toward determining whether methylmercury controls from MS4 entities are needed.

MS4 permittees located upstream of mercury-impaired reservoirs that contain historical mercury mine sites, or gold or silver mine sites where mercury was used, would need to ensure that earth-moving projects will employ erosion and sediment control best management practices to prevent discharge of mercury.

Municipal and Industrial Wastewater Facility Discharges to Mercury-Impaired Reservoirs (Non-Stormwater NPDES Dischargers)

The Water Boards would include the following in the next permit cycle for NPDES-permitted municipal and industrial wastewater facilities that discharge upstream of or directly to impaired reservoirs:

(1) Mercury numeric effluent limitations based on waste load allocations (WLAs);

(2) Require dischargers to monitor total mercury in effluent; and

(3) Require dischargers with treatment pond systems to monitor methylmercury in effluent for up to two years.

In program review after Phase 1, the State Water Board will evaluate these data as a first step toward determining whether methylmercury controls are needed for discharges from treatment pond systems.

Dredging and earth-moving

The Water Boards issue certifications or permits for projects such as dredging in reservoirs and creek channels downstream of mine sites, and earth-moving projects such as construction of roads and watercourse crossings near mines. Future certifications and permits would include requirements for erosion and sediment control best management practices to prevent discharge of mercury.

9.2 Mine Sites Upstream of Mercury-Impaired Reservoirs

This section provides the implementation plan for remediation (cleanup) of mine sites that discharge mercury from historical mines located upstream of mercury-impaired reservoirs. This section supports the actions directed by Mercury Reservoir Provisions Chapter IV.D. during Phase 1 for Tier 1 mine sites.

Herein, "upstream" of mercury-impaired reservoirs means upstream of, adjacent to, or in mercury-impaired reservoirs. Water Board staff developed these recommendations for mine sites based on the analyses in Chapters 6 and 7 and staff's experience with cleanup of mine sites. Note that sections 9.3 and 9.10 also address discharges of mercury from historical mines. Section 9.3 addresses cleanup of mercury-contaminated mining wastes that have been transported by stormwater downstream of mine sites. Section 9.10 addresses activities undertaken for purposes other than cleanup that may discharge mercury from historical mines or mercury from other sources.

9.2.1 Goals and Phasing for Mine Sites

The first goal for cleanup of mine sites is to eliminate discharges of elemental mercury. However, most mining wastes are in the form of mercury contaminated soils and sediments, and not elemental mercury. The second goal is to reduce transport of mercury-contaminated soils and sediments to mercury-impaired reservoirs by restoring the landscape to nearly natural (pre-anthropogenic) erosion and runoff rates by reasonable and feasible means. Excess erosion results from anthropogenic alterations to the land surface that produce, for example, landslides, slumps, gullies, rills, and loss of vegetation. Runoff rates increase due to site development that increases amount of impervious surfaces, which cannot absorb water. Achieving the mine site cleanup goals is expected to provide greater than 90% mercury load reduction (see Appendix I).

These goals for mine site cleanup only consider the benefits to mercury-impaired reservoirs. However, cleanup of mine sites is expected to also have immediate local benefits to receiving waters. Accordingly, the Regional Water Boards may prioritize other mines as high priority for cleanup to improve water quality for parameters other than mercury and in receiving waters (e.g., creeks and rivers) upstream of mercury-impaired reservoirs.

Phasing

Source control actions to address discharges of mercury-contaminated mining wastes from mine sites will be phased (i.e., prioritized) by distance from the reservoir and degree of erosion, as described by the three tiers in Table 9.2. Sites located closer to reservoirs with obvious discharges and active erosion of mercury-contaminated mining wastes will be assigned highest priority (Tier 1). Priority decreases with distance upstream and fewer signs of erosion, in recognition that surrounding watersheds contribute sediment with lower mercury concentrations. Mercury discharges closest to reservoirs will be addressed first because they have a greater and more immediate effect on reservoir sediment inorganic mercury concentrations. Sites located at a greater distance from reservoirs have less effect on reservoir sediment inorganic mercury concentrations, due to greater mixing with increasing transport distance. Specifically, mercury-laden sediment from mine sites mixes with erosion of native soils with lower mercury concentrations during transport through creeks and rivers.

Tiers for mine site prioritization

Staff proposes three tiers for prioritizing mine sites for cleanup:

Tier 1: Significant mercury discharges and watershed characteristics where cleanup will likely result in quick, measurable reductions in reservoir mercury levels.

Tier 2: Significant mercury discharges and watershed characteristics where cleanup is unlikely to result in quick measurable reductions in reservoir fish methylmercury levels (i.e., significant but not Tier 1); and less significant mercury discharges close to a reservoir.

Tier 3: Either no discharge of mercury to a reservoir, or discharge mercury concentration is no more than twice modern background mercury levels.

Cleanup of Tier 1 mine sites should result in quick, measurable reductions in mercury levels in downstream or adjacent reservoirs. Subsequent to reductions in reservoir mercury levels, if all other conditions are unchanged, then according to the linkage analysis, mine site cleanup should result in measurable reductions in reservoir fish methylmercury levels. Staff proposes that Tier 1 sites have all of the following characteristics (also provided on Table 9.2):

1) Reservoir sediment total mercury concentrations are elevated compared to modern background levels for the region. Elevated means equal to or greater than 0.6 mg/kg or 0.2 mg/kg in reservoirs located in geologic regions that are naturally enriched in mercury or have trace levels of mercury, respectively. Elevated mercury indicates the potential for substantial mining waste contributions to the reservoir.

2) All actively eroding mine sites (either significant active erosion from mass wasting processes; or less significant active erosion from small gullies, rills, and accompanying loss of vegetation) in the reservoir watershed are localized to a relatively small area of the reservoir watershed. In other words, (a) mine sites are present on only one or two tributaries of the reservoir, and (b) all mine sites combined cover no more than 10% of the reservoir watershed area. For assessing localized, the reservoir watershed area does not extend beyond any dam on a reservoir tributary. This characteristic of "localized" means that once the mine site(s) is cleaned up, there should no longer be substantial erosion from the mine site. The remainder of the watershed will be a comparatively larger source of clean sediment to the reservoir, consisting of erosion of native soils with lower mercury concentrations.

3) All actively eroding mine sites in the reservoir watershed are located adjacent to or very close to a reservoir. In other words, mine sites that either discharge directly to the reservoir or discharge to a tributary to the reservoir less than about 10 km upstream as measured from reservoir high water level. This characteristic of "not far upstream" recognizes that it is particularly difficult to cleanup mining waste in creek channels; without cleanup, creeks will be very long-term sources of mercury to reservoirs.

4) There are significant discharges of mercury and/or significant active erosion of mining waste. Significant discharges of mercury means average mercury concentration in discharge of mining wastes is greater than 3 mg/kg from mercury mine sites or 1 mg/kg from non-mercury mine sites (i.e., greater than ten times the allocation for geology surrounding mine sites), or elemental mercury is present and being discharged or is likely to discharge. Significant active erosion means mass wasting processes, such as landslides, slumps, and large gullies.

5) Other site-specific factors, approved by a Regional Water Board's Executive Officer, relevant to initiating cleanup and abatement orders within Phase 1. For example, factors could include the identification of viable solvent responsible landowners and/or entities that operated the mines and would ultimately be responsible for mine remediation. In many cases the companies that formerly operated the mines, and even their successor companies, are no longer solvent or existent and this would significantly delay identification of a responsible party with sufficient funds for cleanup.

Tier 2 and 3 mine site characteristics are provided on Table 9.2.

Not all mine sites currently have significant active erosion problems from mass wasting, such as landslides, slumps, and gullies. This is either because they have been cleaned up, or they are small and have been abandoned for such a long time that storms have already transported their erodible wastes downstream and because vegetation may have re-established and thus controlled erosion.

Schedule for mine site cleanup

The Water Boards plan to initiate cleanup of the highest priority mine sites (Tier 1) in Phase 1 of implementation. (Suggested schedules for investigation and cleanup of mine sites are provided in Appendix I.) Schedules for cleanup of lower priority mine sites (Tiers 2 and 3) will be evaluated during program review (see section 9.13.2).

9.2.2 Regulatory Authority and Approach for Mine Sites

The Water Boards plan primarily to use California Water Code authority to compel cleanup of mine sites on lands owned by private parties or owned by state or local agencies. For mine sites on lands owned by federal agencies, the Water Boards may also consider entering into Management Agency Agreements (MAAs). (Federal agencies and the Water Boards have a history of entering into MAAs, as illustrated by two MAAs included in Appendix I.) If the MAAs are not established in a reasonably short period of time, the Water Boards plan to use California Water Code authority to compel cleanup.

The load allocations for mining waste identified in Table 8.1 will be implemented as management practices and are not cleanup standards; mercury concentration or other cleanup standards will be established as necessary and appropriate, typically on a site-specific basis. The waste load allocations (WLAs) for mine sites identified in Table 8.2 will be implemented as numeric effluent limitations (see section 9.7). Cleanup standards are typically based on a risk evaluation that identifies the most sensitive receptor, whether on-site or downstream. Similarly, removal or cleanup of non-soil wastes such as mercury-contaminated machinery, acid mine drainage, portal discharges, and pools of elemental mercury will be addressed as necessary in permits and cleanup orders.

The Water Boards have significant authority to regulate discharges of waste to waters under the Porter-Cologne Water Quality Control Act ("Porter-Cologne Act") (Wat. Code, § 13000 et seq.). For example, the Water Boards issue requirements for submission of technical or monitoring program reports (Wat. Code, § 13267), compel cleanup of waste discharges (Wat. Code,

§ 13304), and issue general or individual waste discharge permits or conditional waivers of waste discharge permits (Wat. Code, §§ 13260 – 13275).

The Water Boards also follow California Code of Regulations, title 27, Division 2, Chapter 7, subchapter 1, beginning with section 22470, which applies to mining waste management. Section 22510 mandates the following performance standard: “New and existing Mining Units shall be closed so that they no longer pose a threat to water quality.”

As required on a site-specific basis, the Water Boards will also use its authority under the federal Clean Water Act for point source discharges and stormwater discharges. The Water Boards have authority under the federal Clean Water Act (pursuant to 33 U.S.C. section 1342) to issue NPDES permits for point source discharges of pollutants. There are nine permittees with individual NPDES permits that regulate portal and other discharges from mine sites, eight of which are responsible for mine sites upstream of 303(d)-listed reservoirs (see Appendix F).

Stormwater discharges that contribute to a violation of a water quality standard or are a significant contributor of pollutants to waters of the United States require NPDES stormwater permits in accordance with the Clean Water Act section 402(p)(2)(E). Accordingly, USEPA promulgated federal regulations for stormwater on 16 November 1990 in Code of Federal Regulations, title 40, Parts 122, 123, and 124. The Water Board’s NPDES industrial stormwater program regulates stormwater discharges from inactive mine facilities. Inactive mine facilities are applicable industries under the stormwater program and are obligated to comply with federal regulations. Accordingly, the State Water Board issued the industrial stormwater general permit order 2014-0057-DWQ (NPDES NO. CAS000001).

9.2.3 Responsible Parties for Mine Sites

Responsible parties under the Statewide Mercury Control Program for Reservoirs are defined as follows (in accordance with Wat. Code, § 13304, subd. (a)):

> Any person…who has caused or permitted, causes or permits, or threatens to cause or permit any waste to be discharged or deposited where it is, or probably will be, discharged into the waters of the state and creates, or threatens to create, a condition of pollution or nuisance, will upon order of the regional board, clean up the waste or abate the effects of the waste, or, in the case of threatened pollution or nuisance, take other necessary remedial action, including, but not limited to, overseeing cleanup and abatement efforts.

Accordingly, responsible parties include, but are not limited to, current mine site property owners and prior mine owners and/or operators. The Water Boards plan to compel current mine site property owners to undertake the implementation actions described herein. In turn, the current mine site property owners may pursue cost recovery or other arrangements with other responsible parties.

Watershed groups and others can help the Water Boards or public agencies identify, prioritize, and implement mine site cleanup. Water Code Chapter 5.7 (Drainage from Abandoned Mines, Wat. Code, §§ 13397 – 13398.9) contains a program for public agencies and cooperating private parties, who are not otherwise legally responsible for abandoned mine lands, to reduce the threat to water quality caused by these lands without becoming responsible for completely cleaning up mining waste from abandoned mines. The Water Boards encourage these parties to participate in this program.

9.2.4 Requirements and Implementation Actions for Mine Sites

Existing requirements

There are thousands of inactive and many abandoned mines in California, many of which are polluting surface water. Mercury mines are primarily located in the Coast Ranges, and mercury is discharging from many gold mines in the Sierra Nevada and elsewhere. Cleanup of mercury mines, including some upstream of reservoirs, was previously required by the mercury TMDLs for San Francisco Bay; Clear Lake; Guadalupe River watershed; Walker Creek watershed; Cache Creek, Bear Creek, and Harley Gulch; Hernandez Reservoir; and Clear Creek (San Benito County). The Water Boards primarily uses its significant California Water Code authority (see section 9.2.2) to compel cleanup of mine sites.

Staff considered and recommends different prioritization approaches for mines on public lands from mines on private lands, as described in the next sections.

Public lands: mine site prioritization and cleanup

For mine sites on public lands, the Water Boards plan to issue orders to federal, state, and local agencies requiring that the agencies prioritize mine sites on land under their jurisdiction. The orders could allow the agencies to (a) develop and implement coordinated inter-agency plans and (b) coordinate cleanup activities for mine sites that extend across lands under different ownership. The Water Boards may seek an MAA (see section 9.2.2) with a federal agency in lieu of issuing orders to meet these requirements. The orders or MAA would direct public agencies to first develop a Mine Site Prioritize Plan, then identify and prioritize mines on public lands, and report their findings in a Mine Site Prioritization Report (each are described in following sections; a suggested sequence of cleanup actions is provided in Appendix I.)

Many public agencies own lands that contain mine sites that discharge mercury-contaminated mining waste. Such public agencies include but are not limited to the federal Bureau of Land Management and Forest Service, and state Departments of Parks and Recreation, Fish and Wildlife, and Forestry and Fire Protection. Further, the USEPA could use its Superfund and other authorities to promptly initiate such investigation and cleanup, and cause the other relevant federal agencies to assume their responsibilities for cleaning up their lands.

Private lands: mine site prioritization

For mine sites on private lands, the Regional Water Boards plan to compel current mine site owners to cleanup Tier 1 mines. (A suggested sequence of cleanup actions is provided in Appendix I.)

Extent of mine sites

Mine site cleanup is not limited to upland mine and processing areas. Instead, mine site cleanup, as needed, will address both upland mine sites as well as adjacent and nearby downslope areas, including waste dumps adjacent to and in creeks. “Mine sites” herein includes associated mining waste near the mine site, and roads or property near the mine site that contain mining waste. Mine sites addressed herein are those that discharge mercury directly to or to tributaries of mercury-impaired reservoirs.

Mercury-contaminated mining waste is located not just at mercury mine sites, but also at gold and silver mine sites where mercury was used in the recovery process. Some mining wastes, such as overburden and processed ores, were commonly dumped onto slopes or into creeks for stormwater to carry them away from the mine processing area. Dredge tailings and dredge fields are mining wastes located in and near creeks and rivers downstream of gold mines, and often are contaminated by mercury.

Mine site prioritization plans

Mine site prioritization plans must describe how responsible parties or Regional Water Boards intend to identify, prioritize in accordance with tiers on Table 9.2, and report their findings. Identification and prioritization plan(s) must describe the following:

(1) Method(s) used to identify and locate mine sites and locate mining wastes associated with each of those mine sites;

(2) Sampling strategy to assess the degree and extent of mercury contamination at the mine sites;

(3) Method(s) to assess actual or potential discharges of mercury from mining to surface waters, including but not limited to, discharges caused by erosion;

(4) Detailed narrative explaining planned methods to interpret results from the sampling strategy and evaluation strategies of items (2) and (3) including a proposed detailed table of contents for the identification and prioritization report;

(5) Plan to prioritize mine sites; and

(6) Schedule for completion of the work described in the plan.

Mine site prioritization plans should evaluate the potential for mercury to be discharged into surface waters. Discharge of both sediment-bound mercury and mercury not attached to sediment (typically elemental mercury) should be evaluated. Discharge of sediment-bound mercury typically results from stormwater erosion and transport of piles mining wastes and mercury-contaminated soils. Investigation plans should compare mercury concentrations in whole—not sieved—soil samples from landslides, slumps, and gullies to the applicable load allocation. The reason for whole soil samples is that these erosion processes deliver a wide range of soil particle sizes, but river transport breaks apart many soil particles. Gravels or any particles greater than 2 mm diameter may be removed from the soil samples because they are not easily analyzed in laboratory equipment. Investigation plans should compare mercury concentrations in sieved (62.5 micron) soil samples from rills and areas that have a loss of vegetation to the applicable load allocation. The reason for sieved soil samples is that these erosion processes typically deliver soil fines.

Mine site prioritization reports

Mine site prioritization reports must report on the findings of mine site investigation and prioritization and include at least the following:

(1) Identification and location of mine sites and mining wastes associated with each of those mine sites;

(2) Findings of amount and concentration of mercury present at each mine site;

(3) Assessment of actual or potential discharges of mercury from mining to surface waters;

(4) Other findings relevant to prioritizing mine sites; and

(5) Prioritization of mine sites in accordance with tiers on Table 9.2.

Implementation (cleanup) actions

Actions to be undertaken to achieve the goal for mine sites will vary depending on site-specific conditions from actions typically used to prevent erosion from construction sites to complex landfill construction. Minimizing or preventing discharge of mercury can be achieved largely through controls, structures, and management practices that achieve best conventional pollutant control technology for erosion and sediment control. However, additional controls may be necessary to prevent discharges of elemental mercury (i.e., mercury not attached to sediment). (A range of expected cleanup actions and basis for anticipated > 90% mercury load reduction are provided in Appendix I.) Mine site cleanup may also need to address other goals not related to mercury in reservoirs, such as reducing on-site risks from inhalation of mercury vapors; addressing discharge of acid mine drainage or elemental mercury; or meeting a site-specific cleanup goal (i.e., mercury concentration in surface soil).

Mine site cleanup plans

After the Regional Water Boards determine which sites are Tier 1 mine sites, they plan to compel responsible parties to develop and submit cleanup plans. Mine site cleanup plans must specify erosion and sediment controls designed to minimize or prevent the discharge of mercury-contaminated sediments and a time schedule to design, permit, construct, install, and test the controls. Erosion and sediment control measures should be designed to minimize or prevent the discharge of mercury from mining in stormwater discharges and authorized non-stormwater discharges.

Mine site cleanup plans must include at least the following:

(1) Proposed designs and specifications to control discharges of mercury from the mine site to surface waters;

(2) A schedule for completion of the mine site cleanup; and

(3) Description of the plans and specifications of the post-construction long-term, operations, maintenance, and monitoring necessary to ensure continued effectiveness of the mine site mercury cleanup control measures.

Mine site cleanup reports

After mine site cleanup actions are completed, they must be reported to the Water Boards (and other permitting agencies, if applicable) via mine site cleanup reports. Mine site cleanup reports must describe the following at a minimum:

(1) Actions taken to control discharges of mercury from mining to surface waters;

(2) Revisions, if any, to the design and specifications for the mercury cleanup control measures;

(3) As-built drawings; and

(4) Revisions, if any, to the post-construction, long-term, operations, maintenance, and monitoring plan(s) necessary to ensure continued effectiveness of the mine site mercury cleanup control measures.

Section 9.2.6 describes monitoring after mine site cleanup to confirm that cleanup remains effective over the long term. The next section discusses other permits for mine site discharges.

9.2.5 Other Permit Considerations for Mine Sites

Mine site discharges may be subject to either or both individual and general NPDES permits.

Mine site discharges subject to individual NPDES permits issued by the State and Regional Water Boards must comply with those permit requirements as well as requirements in the Mercury Reservoir Provisions. Waste load allocations (WLAs) from Tables 8.1 and 8.2 will be incorporated in individual NPDES permits as numeric effluent limitations[1]. These limits will be incorporated either when new individual NPDES permits are issued, or during permit reissuance, which generally occurs at five-year intervals.

Mine site discharges subject to the industrial stormwater general NPDES permit (NPDES No. CAS000001) issued by the State Water Board must comply with those permit requirements. Discharges subject to this and other general NPDES permits are negligible discharges of mercury to reservoirs. Thus, negligible dischargers are not assigned a WLA or other program requirements, and may discharge without a WLA.

Note that in any case, mine site discharges to a 303(d)-listed mercury-impaired creek or river upstream of a mercury-impaired reservoir may be subject in the future to waste load allocations

[1] See section 8.2.4 for an explanation of when a more stringent numeric effluent limitation (i.e., lower mercury concentration limit) may apply to point source discharges to a creek or river upstream of a mercury-impaired reservoir to protect beneficial uses of the receiving water

and corresponding numeric effluent limitations adopted after the effective date of the Mercury Reservoir Provisions. This would occur after TMDLs are approved for the upstream impaired rivers and creeks.

9.2.6 Tracking, Reporting, and Monitoring for Mine Sites

Monitoring and reporting to the applicable Regional Water Board is needed over the long term to confirm that mine site cleanup actions remain effective and mercury controls are functioning properly. Accordingly, cleanup orders and waste discharge permits issued by the Water Boards will require responsible parties to develop and implement post-cleanup maintenance, monitoring, and reporting plans. The purpose of this maintenance and monitoring is to ensure that mine site cleanup actions continue to be effective, and if not, to determine why not, and to fix the problem. These and other applicable monitoring requirements are described in Chapter 10.

9.3 Mining Waste Downstream of Mine Sites but Upstream of Mercury-Impaired Reservoirs

This section provides the implementation plan for remediation (cleanup) of mining wastes accumulated in creeks, floodplains, and reservoirs that discharge mercury from historical mines to mercury-impaired reservoirs. In other words, this section addresses mercury previously discharged from mercury-contaminated mine sites that has accumulated in areas upstream of, adjacent to, or in mercury-impaired reservoirs (“downstream sites”).

This section builds from Chapter 6 (Source Assessment). For reasons provided in Chapter 7 (Assessment of Allocation and Implementation Options), no implementation actions are proposed for this mercury source during Phase 1. Hence, the Mercury Reservoir Provisions do not direct any actions for mercury discharges from downstream sites during Phase 1.

Herein, “upstream” of mercury-impaired reservoirs means upstream of, adjacent to, or in mercury-impaired reservoirs. Note that sections 9.2 and 9.9 also address discharges of mercury from historical mines. Section 9.2 addresses cleanup of mercury-contaminated mine sites located upstream of mercury-impaired reservoirs. Section 9.9 addresses activities undertaken for purposes other than cleanup that discharge mercury from historical mines.

9.3.1 Goals and Phasing for Downstream Sites

The goal for cleanup of mercury-contaminated downstream sites is restoration to a stable configuration that minimizes excessive erosion or deposition of mercury-contaminated mining waste and/or mercury-laden sediment by reasonable and feasible means.

However, downstream sites are affected by upstream sites. Consequently, upstream mine sites should be remediated prior to remediating downstream sites. This phasing of cleanup avoids re-contaminating downstream sites from upstream mercury sources. The State Water Board will evaluate the timing for cleanup of downstream sites in program review at the end of Phase 1 of implementation (see section 9.13.2). Concepts the State Water Board may consider for cleanup of downstream sites are provided in Appendix I.

9.4 Atmospheric Deposition

This section provides the implementation plan for mercury from atmospheric deposition to California. This section supports the recommendations in the Mercury Reservoir Provisions Chapter IV.C. during Phase 1 for atmospheric deposition.

9.4.1 Goals and Phasing for Atmospheric Deposition

The primary goal for Phase 1 is to determine whether there is a trend of increasing or decreasing atmospheric deposition during Phase 1. Not knowing the trend could confound interpretation of reservoir pilot test results. Secondary goals for Phase 1 are to monitor and model atmospheric deposition of mercury in California and assess whether load allocations for California and global anthropogenic sources will be attained in Phase 2. The goal for Phase 2 is to attain the allocations for anthropogenic sources. These goals reflect the fact that atmospheric deposition of mercury from natural sources is not controllable. Water Board staff developed this recommended implementation plan for atmospheric deposition based particularly on the analyses in Chapters 6 and 7.

California has, through both voluntary and regulatory approaches, reduced anthropogenic emissions by more than 50% between 2001 and 2008. California is expected to achieve the load allocation for deposition attributed to California anthropogenic emissions by the end of Phase 1 through implementation of USEPA, California Air Resources Board (CARB), and local air district regulations.

However, California clearly is dependent upon other states and countries to reduce emissions to achieve the load allocation for global anthropogenic emissions. USEPA and other states' regulations are expected to continue to greatly reduce U.S. anthropogenic contributions to the global atmospheric pool of mercury. In contrast, there is uncertainty about when and whether anthropogenic emission sources outside of the U.S. will be reduced or will continue to increase, particularly sources related to economic development in Asia.

Mercury from atmospheric deposition is widely regarded as the most bioavailable source of mercury. Scientists and policy analysts around the world are actively studying mercury emissions and deposition patterns. It is currently anticipated that mercury emissions will increase for the next couple of decades before air pollution controls are tightened in developing countries and artisanal gold miners stop using mercury (see Chapters 6 and 7). A statewide increasing trend in atmospheric deposition could obscure the beneficial effects of reservoir management actions to reduce methylmercury production and bioaccumulation. In the absence of awareness of such a trend, false conclusions could be drawn that actions are not having the desired effect.

On the other hand, economic or other conditions could change quickly and cause mercury emissions to decrease during Phase 1 reservoir pilot tests. The existence of a general declining trend in atmospheric deposition could give the impression that reservoir pilot tests were more effective than they actually were. Therefore, State and Regional Water Board staff will perform a review and analysis of the then-current scientific literature to identify whether there was an increasing or decreasing trend in atmospheric deposition coincident with Phase 1 reservoir pilot tests. This literature review will be considered in program review at the conclusion of Phase 1 (see section 9.13.2).

Alternatively, CARB and USEPA or other organizations may elect to monitor and model atmospheric deposition. The model results could then be assessed as to whether allocations for atmospheric deposition attributed to anthropogenic sources are or are not likely to be attained. More information is provided in Appendix I.

9.5 Urban Runoff to Mercury-Impaired Reservoirs ("Storm Water NPDES Dischargers")

This section provides the implementation plan for urban runoff regulated by municipal separate storm sewer systems (MS4s) NPDES permits issued to municipalities. This section supports the actions directed by Mercury Reservoir Provisions Chapter IV.H during Phase 1 for storm water NPDES-permitted dischargers.

This plan applies to urban runoff conveyed via storm drain networks either directly to or to tributaries of mercury-impaired reservoirs. Water Board staff developed this recommended implementation plan for urban runoff based on the analyses in Chapters 6 and 7.

9.5.1 Goals and Phasing for Urban Runoff

The first goal for urban runoff in Phase 1 of implementation is to ensure that construction activities undertaken in areas affected by mercury from legacy mining take appropriate measures to prevent or control mercury from being discharged in stormwater. The second goal for urban runoff is to determine whether municipal separate storm sewer systems (MS4s) cause inorganic mercury to be methylated at higher rates compared to other watershed areas, and therefore whether urban runoff contributes significantly to elevated levels of methylmercury in fish compared to other upland inputs. The monitoring results will be evaluated by Water Board staff during the program review planned at the conclusion of Phase 1. Potential outcomes of the evaluation include: recommendations for no more monitoring; more monitoring needed; no need for; and/or need or potential need for MS4 methylmercury control actions, and if so, steps to identify where and how methylation in MS4s could be controlled.

Schedule for urban runoff

During Phase 1 of implementation, the Water Boards will incorporate requirements to control discharges of mercury from historical mining and methylmercury monitoring in MS4 NPDES permits specified in section 9.5.4 during permit reissuance, which generally occurs at five-year intervals. Hence, if not already required, the legacy mining and methylmercury monitoring requirements should be incorporated into permits by the end of year 6 of Phase 1 of implementation. Methylmercury monitoring and reporting should be completed within Phase 1 of implementation so the results can be evaluated during the program review planned at the end of Phase 1 of implementation (see section 9.13.2, in particular focusing question 2.d). The program review at the end of Phase 1should evaluate whether it is appropriate to require additional methylmercury monitoring by NPDES-permitted MS4s.

MS4 permits already include actions that will reduce mercury in discharges, as described in Chapter 7. Therefore, no additional mercury control actions are included in Phase 1 of implementation. However, the program review will re-evaluate urban runoff discharges to determine if further inorganic mercury and new methylmercury control actions should be required during Phase 2 in order for this statewide program as a whole to attain all TMDL targets applicable to each reservoir.

9.5.2 Regulatory Authority and Approach for Urban Runoff

The Water Boards have authority under the federal Clean Water Act and State Water Code to issue NPDES permits for point source discharges of pollutants, including MS4s. The Water Boards plan to incorporate the implementation and monitoring and reporting requirements described in section 9.5.5 into MS4 NPDES permits issued by the Water Boards when the applicable permits are reissued.

9.5.3 Responsible Parties for Urban Runoff

The parties responsible for urban runoff from developed areas in reservoir watersheds are the MS4 NPDES permittees for the storm drain networks that convey urban runoff from into mercury-impaired reservoirs. The storm drain networks discharge either directly to mercury-impaired reservoirs or discharge into tributaries upstream of mercury-impaired reservoirs. Implementation and monitoring and reporting requirements apply to the subset of MS4 NPDES permittees identified in the next sections.

9.5.4 Requirements and Implementation Actions for Urban Runoff

The purpose of the urban runoff (MS4 NPDES permittees) actions is to ensure that construction activities do not discharge mercury from historical mining areas to impaired reservoirs (see section 7.2.3). The applicable MS4 NPDES permittees are those which have an MS4 service area encompasses one or more historical mine sites, as identified by U.S. Geological Survey (USGS) topographical maps; USGS or other historical mine site databases; municipal or other historical records; or site inspections. Applicable projects are construction activities that involve earth moving, such as but not limited to road construction, road maintenance, and land development activities.

The MS4 NPDES permittees would need to ensure that construction activities employ effective erosion control measures, such as those required by the General Permit for Discharges of Storm Water Associated with Construction Activity (Construction General Permit). The MS4 NPDES permittees would need to require that entities and landowners who apply for permits for applicable projects implement erosion and sediment control practices to minimize discharges of mercury. The MS4 NPDES permittees could accomplish this, for example, by requiring agencies and landowners who apply for permits for applicable projects to submit a plan to the MS4 NPDES permittee that includes erosion estimates, erosion control practices, and, if a net increase in erosion is expected to occur, a remediation plan; and the applicant implement practices to control erosion.

9.5.5 Tracking, Reporting, and Monitoring for Urban Runoff

Monitoring of methylmercury in urban runoff is necessary to identify whether MS4 discharges make greater contributions to fish methylmercury levels in the dry season than in the wet season (see Chapters 5 and 6) to inform the program review at the end of Phase 1 (see section 9.13.2). As described in Chapter 7, such methylmercury monitoring should be conducted in watersheds of impaired reservoirs are that are highly urbanized where there may be an increase likelihood of observing a difference in methylmercury levels in discharges, if in fact urban runoff infrastructure increases methylation of mercury. Characteristics of highly urbanized means more than 20 percent developed and there is an MS4 storm drain network that conveys urban runoff directly to the reservoir or to its tributaries. Characteristics of highly urbanized also means the applicable individual MS4 NPDES permittees are those which serve a population of 100,000 or more and the combined drainage infrastructure area of all MS4 NPDES permittees in the watershed is greater than 20 percent of the watershed area upstream of the impaired reservoir. Urbanized land may be evaluated as a proxy for MS4s NPDES permittee drainage infrastructure area (as was done for the source assessment in Chapter 6) because map data for urbanized land are readily available; map data are not readily available for MS4s drainage infrastructure, service, or jurisdictional areas. The reservoir watershed area upstream of the impaired reservoir does not extend upstream of any dam on a tributary.

Monitoring procedures are described in Chapter 10. Monitoring must occur in both wet and dry seasons. Results should be evaluated for differences in methylmercury concentrations between seasons. If flow estimates are available, results should also be evaluated for differences in estimated loads of methylmercury between seasons.

9.6 Runoff from Non-urbanized Upland Areas to Mercury-Impaired Reservoirs

This section provides the implementation plan for runoff from areas with mercury-contaminated soils located upstream of impaired reservoirs.

This section builds from Chapter 6 (Source Assessment). For reasons provided in Chapter 7 (Assessment of Allocation and Implementation Options), no on-the-ground implementation actions are proposed for this mercury source during Phase 1. Hence, the Mercury Reservoir Provisions do not direct any actions for runoff from non-urbanized upland areas during Phase 1.

This implementation plan for runoff from non-urbanized upland areas is based on the analyses in Chapters 6 and 7.

9.6.1 Goals and Phasing for Non-urbanized Upland Areas

The goal for mercury from non-urbanized upland areas is to reduce anthropogenic soil erosion and hence reduce transport of mercury to reservoirs by restoring the landscape to nearly natural (pre-anthropogenic) erosion and runoff rates by reasonable and feasible means.

In general, the Water Boards plan to rely on existing regulatory programs that require best management practices to control anthropogenic soil erosion (see section 7.2.4). Reliance on existing programs rather than developing new requirements is appropriate because the State and Regional Water Boards have many existing regulatory programs to address sediment pollution problems, which will simultaneously address mercury pollution.

However, scientists around the world are actively studying mercury discharges and cycling from lands used for forestry and timber harvest. This research may advance significantly during the course of Phase 1 of implementation. Therefore, Water Board staff may perform a review and analysis of the scientific literature on the effects of forestry and timber management on methylation and fish methylmercury levels in downstream reservoirs and lakes. This literature review could be considered in program review at the conclusion of Phase 1 (see section 9.13.2).

9.7 Municipal and Industrial Wastewater Facility Discharges to Mercury-Impaired Reservoirs ("Non-Stormwater NPDES Dischargers")

This section provides the implementation plan for municipal and industrial wastewater treatment facilities with NPDES non-stormwater permits that discharge either directly to or to tributaries of mercury-impaired reservoirs. This section supports the actions directed by Mercury Reservoir Provisions Chapter IV.G during Phase 1 for mercury discharges by non-stormwater NPDES dischargers ("dischargers"). Whereas previous Chapters herein use the term "facility discharges," for consistency with the Mercury Reservoir Provisions this Chapter uses "dischargers."

This implementation plan for municipal and industrial wastewater non-stormwater NPDES dischargers is based on the analyses in Chapters 6 and 7, and CWA section 303(d)(4)(A) mandates that NPDES permits must have effluent limitations based on waste load allocations. Negligible dischargers are subject to either general permits or, if subject to individual NPDES permits, they have design discharge flows equal to or less than 0.2 million gallons per day. Negligible dischargers are not assigned a waste load allocation and can discharge without a waste load allocation or corresponding effluent limitation.

9.7.1 Goals and Phasing for Municipal and Industrial Wastewater Facility Dischargers

The goal for dischargers is to maintain proper operation, maintenance, and performance of wastewater treatment to ensure low total mercury levels in discharges. Chapter 6 describes that properly operated and maintained wastewater treatment facilities that meet existing permit requirements for other pollutants have low levels of mercury in their discharges. Implementation includes the following:

(a) Waste load allocations from Tables 8.1 and 8.2;

(b) Numeric effluent limitations based on waste load allocations from Table 8.1 that will be incorporated into NPDES permits; and

(c) Monitoring.

Schedule for Municipal and Industrial Wastewater Facility Dischargers

Generally, NPDES permits are reissued every five years. Subsequent to the effective date of the Mercury Reservoir Provisions, in the next reissuance of existing NPDES permits for dischargers, or in the issuance of new NPDES permits to dischargers, the Water Boards plan to incorporate total mercury numeric effluent limitations and require dischargers listed in Table 8.2 to monitor and report on total mercury levels in discharges (see section 9.7.4). Additionally, the program review (see section 9.13.2) may re-evaluate Phase 1 total mercury monitoring data from dischargers to determine if reductions in total mercury discharges are necessary to attain all TMDL targets applicable to reservoirs.

Within one year of the effective date of the Mercury Reservoir Provisions, the Water Boards plan to require dischargers that use treatment pond systems and therefore typically have higher methylmercury concentrations in their discharges (see section 7.2.6) to monitor and report on methylmercury levels in discharges. The Water Boards plan to either issue orders pursuant to Water Code sections 13267 or 13383, or modify, reissue, or adopt the applicable NPDES permit to require effluent methylmercury monitoring for one or two years (see section 9.7.5). Methylmercury monitoring and reporting should be completed during Phase 1 to allow for the results to be evaluated during the program review planned at the end of Phase 1 (see section 9.13.2). The program review will evaluate whether it is necessary and appropriate to require that other non-stormwater NPDES dischargers perform methylmercury monitoring.

9.7.2 Regulatory Authority and Approach for Municipal and Industrial Wastewater Facility Dischargers

Waste load allocations and numeric effluent limitations

The Water Boards have authority under the federal Clean Water Act and California Water Code to issue NPDES permits for point source discharges of pollutants and NPDES permits must include water quality based effluent limitations that are consistent with the assumptions and requirements of any available wasteload allocations The waste load allocations in Tables 8.1 and 8.2, or determined for new discharges via Figure 8.1 or the equivalent Figure 1 in the Mercury Reservoir Provisions, will be incorporated as average annual numeric effluent limitations in NPDES permits for dischargers that discharge more than 0.2 million gallons per day (design flow) either directly to or to tributaries of mercury-impaired reservoirs listed in Table 9.1. The waste load allocations were based on an evaluation of effluent data from existing facilities and set at levels consistent with current discharge levels. Implementation of the wasteload allocations as average annual numeric effluent limitations is consistent with the derivation of the waste load allocations. As described in Chapter 7, these discharges are not a significant mercury source to mercury-impaired reservoirs; are expected to decrease for several reasons; the waste load allocations are appropriately rigorous to ensure dischargers maintain proper wastewater treatment; and the waste load allocations are feasible to achieve.

As described in Chapter 8, more stringent numeric effluent limitations may apply to non-stormwater NPDES discharges to a tributary to a mercury-impaired reservoir to protect beneficial uses of the receiving water. For example, for discharges to a 303(d)-listed mercury-impaired creek or river upstream of a mercury-impaired reservoir, a more stringent waste load allocation or numeric effluent limitation may apply in the future when TMDLs are developed for the upstream impaired rivers and creeks.

As described in section 8.2.4, the waste load allocations account for future growth in existing and new discharges. The numeric effluent limitations are discharge limits for calendar year average effluent total mercury concentrations. The waste load allocations and numeric effluent limitations apply to the total effluent of a waste discharge at the end-of-pipe, except for situations described in section 8.2.4.

9.7.3 Responsible Parties (Non-Stormwater NPDES Dischargers)

The parties responsible for non-stormwater NPDES discharges are the dischargers named in the NPDES permits for municipal and industrial facilities that discharge either directly to or to tributaries of mercury-impaired reservoirs listed in Table 9.1. The dischargers subject to waste load allocations and other implementation requirements are identified in Table 8.2.

9.7.4 Requirements and Implementation Actions for Municipal and Industrial Wastewater Facility Dischargers

As discussed in section 9.7.2, the Water Boards will incorporate the total mercury waste load allocations as total mercury numeric effluent limitations in non-stormwater NPDES permits. In addition, the Water Boards will include in non-stormwater NPDES permits the applicable discharge mercury monitoring and reporting procedures described in Chapter 10.

Implementation actions

Actions necessary for compliance with the total mercury waste load allocations begin with maintaining efficiency of existing wastewater treatment processes and pretreatment programs, including when discharge volumes increase. However, mercury in municipal wastewater influent is expected to decrease because, as stated in section 6.5.1, the peak production and use of mercury-containing products occurred decades ago, and efforts to eliminate the remaining uses are ongoing.

Similarly, the presence of mercury even at trace levels in products used by industry and in wastewater treatment processes is expected to decrease. In addition, treatment upgrades implemented to address other pollutants (e.g., new ammonia numeric effluent limitations and Title 22 or equivalent tertiary treatment requirements, see section 7.2.5) often decrease effluent mercury concentrations.

As a result of decreased use of mercury and maintaining good treatment performance, it is expected that the effluent mercury concentrations will remain the same or decrease, and the waste load allocations will not be exceeded.

9.7.5 Tracking, Monitoring, and Reporting for Municipal and Industrial Wastewater Facility Dischargers

Total mercury effluent monitoring and reporting frequency will be determined by the applicable Regional Water Board in the permit process and accounting for considerations described in section 7.2.5. Monitoring of total mercury in effluent is needed to assess compliance with numeric effluent limitations and hence compliance with waste load allocations.

Methylmercury monitoring by dischargers that use one or more treatment pond systems (see sections 7.2.5 and 7.2.6) in addition to total mercury monitoring is needed to inform the program review at the end of Phase 1 (see section 9.13.2). Methylmercury effluent monitoring frequency should be quarterly for up to two years to identify seasonal trends and relative magnitude of methylmercury in non-stormwater discharges. During program review it will be determined whether non-stormwater dischargers need to perform other methylmercury monitoring or control actions during Phase 2 to attain all TMDL targets applicable to each reservoir (see Chapter 8 for more discussion). Methylmercury monitoring and reporting procedures are described in Chapter 10.

See Chapter 10 for more details on total and methylmercury monitoring and methylmercury reporting procedures. NPDES permit programs already provide for extensive tracking and reporting procedures by dischargers and Water Boards. Monitoring of total mercury and methylmercury, where it is not already required, would be a new component of these programs.

9.8 Reservoir Water Chemistry Management Actions for Mercury-Impaired Reservoirs

This section describes the implementation plan to address water chemistry in mercury-impaired reservoirs. This section supports the actions directed by Mercury Reservoir Provisions Chapter IV.F during Phase 1 for management of reservoir water chemistry.

This implementation plan for water chemistry is based on the review of scientific literature in Chapter 4, analyses in Chapter 7, and staff’s experience with implementation of other mercury TMDLs that include a load allocation for reservoir aqueous methylmercury.

9.8.1 Phase 1 Actions for Reservoir Water Chemistry Management

The Mercury Reservoir Provisions direct that the actions in Phase 1 are to complete pilot tests of water chemistry management to control methylmercury production in reservoirs. Reservoirs that are part of hydropower projects licensed by the Federal Energy Regulatory Commission (“FERC-licensed”) would be excluded from mercury pilot test requirements in Phase 1 (see section 9.8.2).

The Water Boards encourage multi-party collaborative and targeted efforts for Phase 1 pilot tests and associated studies (see section 9.8.3). Credit for actions initiated or completed prior to State Water Board adoption of the Mercury Reservoir Provisions is described in section 9.8.9

The goal of the pilot tests is to determine whether management actions reduce fish methylmercury levels. A successful pilot test is one that allows determination of whether a management action is successful <u>or not</u> in measurably reducing fish methylmercury levels. Note that the aqueous methylmercury load allocation is being implemented as a management practice with the goal of achieving all TMDL targets applicable to each reservoir and not as a cleanup standard or a numeric effluent limitation.

Phase 1 pilot tests

Phase 1 pilot tests of different reservoir water chemistry management practices are needed to determine actions to meet the goal of reducing fish methylmercury levels. Phase 1 actions have the following components: (a) include studies to characterize methylmercury production and bioaccumulation in reservoirs; (b) include pilot tests of reservoir management practices to reduce methylmercury production; and (c), if pilot testing fisheries management practices, should be coordinated with fisheries managers and include consulting with the California Department of Fish and Wildlife regarding fisheries management practices to reduce bioaccumulation. Reservoir management actions could address in-reservoir methylmercury production and possibly address demethylation. The pilot tests could evaluate and account for statistically significant differences in methylmercury production between locations within a reservoir, because this may allow for long-term actions to be focused on subsections of reservoirs rather than on the entire reservoir.

The Mercury Reservoir Provisions require reservoir owners and operators to conduct reservoir pilot tests to develop and evaluate a range of reasonable and practicable management practices that could be implemented within each of their impaired reservoir(s) to attain all TMDL targets applicable to each of their impaired reservoir(s).

The scope of reservoir water chemistry management actions to be evaluated include the following (from Chapter 7):

- Oxidant addition to reservoir bottom waters (near the sediment-water interface) to reduce anoxia or adjust redox potential when reservoirs are stratified to suppress methylation of mercury. Evaluate various oxidants (e.g., dissolved oxygen, ozone, nitrate, others) for (a) efficacy for methylmercury reduction, (b) multiple benefits (e.g., drinking water quality, algal controls), and (c) avoidance of adverse consequences (e.g., application only when a reservoir is stratified and not discharging bottom waters from the dam, with monitoring to ensure that added oxidant does not increase nutrient levels in the reservoir or downstream; see section 7.3.2);
- In-reservoir sediment cleanup (removal or encapsulation) to address inorganic mercury hotspots such as submerged or near-shore mine sites and mining waste (if upstream sources have already been controlled, so that the reservoir will not be re-contaminated);
- Other potentially controllable methylation factors, including methods to enhance demethylation, described in Chapters 4 and 7 or which may be described in scientific literature after 2012 and, therefore, not included in Chapter 4.

(The scope of fisheries management actions to be evaluated is described in section 9.9.)

Additionally, the locations of pilot tests could be selected for the following attributes:

- Protect human health and wildlife by selecting reservoirs with sport fish methylmercury concentrations of 0.7 mg/kg or higher. Methylmercury of 0.7 mg/kg is more than three times the TMDL sport fish target; about 20 percent of the 303(d)-listed reservoirs have fish methylmercury levels above 0.7 mg/kg.
- Protect human consumers by selecting reservoirs with highest consumption rate of sport fish.

- Protect wildlife by selecting reservoirs with highest piscivorous bird population density, either seasonal (migratory) or year-round resident birds.
- Locate tests in different geographic regions.
- Select only small or medium-size reservoirs, or one smaller arm of large reservoirs, for Phase 1 pilot tests.

Technical Review Committee

An independent, third-party Technical Review Committee is needed to assure the reservoir owners and operators, fisheries managers, Water Boards, and concerned public that pilot tests are conducted with high scientific merit and address reservoir (and fisheries) operating constraints. One Technical Review Committee should be convened that encompasses both water chemistry and fisheries management for efficiency and effective communications (see section 9.8.8).

Technical adequacy of pilot tests

An important benefit of the Technical Review Committee is advice on scientific components of pilot test work plan such as baseline monitoring, monitoring pilot test effectiveness, and pilot test procedures. The Technical Review Committee's advice should improve the technical validity and efficiency of pilot tests.

Considerations for baseline and effectiveness monitoring include collecting adequate numbers of samples to provide for statistical significance of pilot test results, i.e., meaningful comparison of "before" and "after" reservoir mercury conditions. A sufficient number of samples supports meaningful comparisons even for small changes, but too many samples are not cost effective. Other considerations for baseline and pilot test monitoring include, but are not limited to, sample seasonality, frequency, and locations; matrices (sediment, water, biota); selection of field instruments; and laboratory analytes.

Considerations of pilot test procedures could include control (i.e., "reference") reservoirs. Pairing similar test and control reservoirs could help to minimize effects of climate and environmental factors that could confound results. Control reservoirs could be located in the same watershed and have generally similar characteristics; physical characteristics (e.g., shape and depth), biological characteristics (e.g., similar fish assemblage and nutrient inputs), and similar water drawdown. Alternatively, test and control sites could be located in distinct areas within the same reservoir, provided the pilot test reservoir is sufficiently large and the test is confined to a portion of the reservoir.

In addition to control reservoirs, the Technical Review Committee may advise that associated studies be conducted. Studies consist of field and laboratory measurements, whereas pilot tests consist of field applications of reservoir water chemistry management actions. Associated studies might consist of, for example, monitoring baseline methylmercury conditions in both test and control reservoirs prior to starting pilot tests. Also, an associated study might be specific to the proposed pilot test, for example, measuring oxygen demand in the test reservoir for use in designing an oxygenation system. Yet another associated study that would help to ensure correct interpretation of pilot test results is monitoring statewide trends in largemouth bass (see Chapter 10).

Proposed Phase 1 pilot tests

Table 9.3 contains preliminary recommendations for pilot tests, associated studies, and control sites. Studies also could evaluate seasonal and inter-annual variation in fish and aqueous methylmercury levels, to help distinguish between effects of pilot tests and these temporal variations.

Pilot tests may also help with evaluating the feasibility of reducing methylmercury production or bioaccumulation more than the minimum needed to attain all TMDL targets applicable to each reservoir. This evaluation would happen during the program review (see section 9.13.2). Reducing methylmercury production or bioaccumulation to lower than the minimum to attain targets could provide an additional margin of safety or perhaps allow people to consume locally-caught fish at rates higher than 32 grams per day (one meal per week).

9.8.2 Responsible Parties and Regulatory Authority for Reservoir Water Chemistry

Reservoir owners and operators are the responsible parties for reservoir water chemistry management. Reservoirs that are part of hydropower projects licensed by the Federal Energy Regulatory Commission ("FERC-licensed") are excluded from mercury pilot test requirements in Phase 1.

The Water Boards have authority to regulate and enforce water quality control requirements under the Porter-Cologne Act (Wat. Code, § 13000 et seq.). For example, the Water Boards issue requirements for submission of technical or monitoring program reports (Wat. Code, § 13267), compel cleanup and abatement of waste discharges (Wat. Code, § 13304), and issue general or individual waste discharge permits (Wat. Code, §§ 13260 – 13275). To compel pilot tests in Phase 1, the Water Boards will issue a California Water Code section 13267 technical report requirement or other appropriate order to each owner and operator of each non-FERC-licensed impaired reservoir, as described in section 9.8.5. Also, State agencies, offices, departments, and boards must comply with water quality control plans approved or adopted by the State Water Board unless otherwise directed or authorized by statute (Wat. Code, § 13247).

The Water Boards' regulatory authorities differ for FERC-licensed reservoirs. While the Federal Power Act generally preempts state law over FERC-licensed, single-purpose hydroelectric projects—it does not preempt application of other federal laws. Section 401 of the federal Clean Water Act provides the Water Board's regulatory authorities for single-purpose FERC-licensed projects on reservoirs. The Water Boards also have additional authorities for multi-purpose FERC-licensed projects on reservoirs, namely Water Code section 275, the public trust doctrine, and Water Code section 1258.

FERC regulates hydroelectric projects via the Federal Power Act. The Federal Power Act generally preempts the exercise of independent state law authority to regulate the water quality or environmental effects of FERC-licensed hydroelectric facilities, even where the requirements imposed by the state do not conflict with the FERC license. There are substantial exceptions to this preemption, however, including state regulation of diversion or use of water for uses other than hydroelectric power at multi-use facilities that have FERC licenses for hydroelectric power, and state control over facilities owned or operated by the state or a political subdivision of the state. Additionally, the Federal Power Act does not limit application of federal Clean Water Act requirements, including the State Water Board from exercise of its water quality certification authority under section 401 of the Clean Water Act. Such inclusion could occur when Clean Water Act section 401 certification is required for the original FERC license or for FERC relicensing. In addition, a previously issued 401 certification may be revised where the revision is within the scope of a reservation of authority made in the previously issued 401 certification, without waiting until the project comes up for FERC relicensing.

9.8.3 Coordinated Approach

The Water Boards prefer a coordinated approach (i.e., multi-party collaborative and targeted effort) for Phase 1 pilot tests including reservoir owners and operators and fisheries managers. To that end, the Water Boards encourage reservoir owners and operators to coordinate and collaborate amongst themselves and with entities that stock and manage fish in their reservoirs.

A coordinated approach provides several opportunities for cost savings. The main category of cost savings comes from conducting fewer, targeted studies in representative reservoirs. These coordinated pilot tests could provide equivalent information at much less cost than conducting studies in all impaired reservoirs. Another category of cost savings is staff expertise. Coordination would allow reservoir owners and operators to, in essence, share staff with specialized expertise in mercury cycling and bioaccumulation, rather than each owner and operator needing to hire expert staff.

Representative reservoirs

A major advantage to a coordinated approach is that pilot tests could be conducted in fewer, targeted reservoirs rather than in all impaired reservoirs. Such targeted reservoirs must be "representative reservoirs," meaning that the management practices pilot tested at a specific reservoir or reservoirs are expected to be effective to aid in achieving the applicable targets in each similar reservoir included in the coordinated approach. This aspect of representativeness should be verified with the Technical Review Committee (see section 9.8.8).

Coincidentally, control actions that might reduce fish methylmercury levels may be planned for non-assessed reservoirs ("non-assessed" is defined in Chapter 1). For example, control actions may be planned for manganese, taste and odor problems, or cyanobacteria, and these control actions may affect fish methylmercury levels. Accordingly, pilot tests may be conducted in non-assessed representative reservoirs and not only in impaired reservoirs. Studies in non-impaired reservoirs—particularly in reservoirs with very low fish methylmercury levels—are appropriate to identify why these reservoirs have such low fish methylmercury levels and whether these conditions are reproducible in impaired reservoirs. Non- assessed reservoirs proposed for pilot tests must also be verified with the Technical Review Committee that they are representative reservoirs.

Additionally, for a reservoir to qualify as "representative reservoir" all associated reservoirs owners and operators must provide assurance that the management practices pilot tested in the representative reservoir have the potential to be operationally feasible to implement in each associated reservoir.

Representative reservoirs are subject to review and approval by the Water Boards, via review and approval of the pilot test work plan.

Coordinated approach

Key features of a coordinated approach acceptable to the Water Boards are the following:

- Preferably one statewide work plan that addresses pilot tests for both reservoir water chemistry and fisheries management, but up to three work plans for reservoir management and three work plans for fisheries management are acceptable.
- Reservoirs included in a coordinated approach must be representative of all of the reservoirs of those entities participating in the coordinated effort.
- Where practicable, pilot tests and associated studies could be coordinated with other mercury and methylmercury monitoring efforts.

Pilot tests conducted in representative reservoirs must provide information to help answer management questions 1 and 2 in section 9.13.2. For example, some management questions are the following:

- Where is methylation occurring in the system and what are the controlling factors?
- How do reservoirs differ from one another, and how should the Statewide Mercury Control Program for Reservoirs account for these differences?
- Are within-reservoir processes the most important factors for elevated fish methylmercury levels? Could external methylmercury sources also be important factors?
- Are there localized, within-reservoir, methylation effects?

Pilot tests already underway in accordance with previously adopted mercury TMDLs will not count towards pilot tests for the Statewide Mercury Control Program for Reservoirs. For example, Soulajule Reservoir (because planning for pilot tests is already underway in accordance with the Walker Creek watershed mercury TMDL), and Almaden Reservoir, Lake Almaden, Calero Reservoir, and Guadalupe Reservoir (because pilot tests are already underway in these reservoirs in accordance with the Guadalupe River watershed mercury TMDL). Nonetheless, the reservoir owners and operators may participate in a statewide coordinated approach for their impaired reservoirs, and available data and results from the pilot tests already underway may be included and evaluated in coordinated program reports.

Mechanisms of coordination

The coordinated approach must be formalized with a binding agreement signed by all participants and submitted to the Water Boards, such as a Memorandum of Understanding. The agreement must contain at least the following provisions:

(1) The name of each owner, operator, and their impaired reservoir(s) subject to the coordinated approach, and if applicable, any of their impaired reservoir(s) not subject to the coordinated approach;

(2) The specific actions each owner and operator agrees to undertake with respect to developing and implementing the pilot tests;

(3) An outline of the following: (a) proposed preliminary selection criteria for representative reservoirs; (b) preliminary ideas for how the pilot tests will be designed to be representative of the similar impaired reservoirs involved; (c) proposed preliminary selection criteria for control reservoirs; and (d) describe preliminary proposed associated studies in non-impaired reservoirs;

(4) A description of the financial and other resource commitments from each owner and operator; and

(5) A statement signed by an authorized representative of owner(s) and operator(s) committing to develop and implement the pilot test(s).

9.8.4 Work Plans and Reports

This section describes the work plans and reports required to support coordinated and individual pilot tests. Individual work plans must be submitted for each impaired reservoir that is not included in a coordinated pilot test approach. (Whereas this section describes the content of work plans and reports, the following section [9.8.5] provides the schedule for conducting pilot tests and submitting work plans and reports.)

Each work plan must describe and justify proposed pilot tests as described in the following two sections (regarding coordinated and individual pilot test work plans), including time schedules. The time schedule must include the following, at a minimum: (a) projected start date for the pilot test, (b) projected completion date of pilot test; and (c) reporting dates. Also, the time schedule should accommodate permitting. For example, it will likely be necessary to obtain individual or a general Waste Discharge Requirements or other permits from the Water Boards prior to chemical addition (other than addition of oxygen), and individual Waste Discharge Requirements or other permits for sediment cleanup. Permits may also be needed from other agencies.

Coordinated pilot test work plan

A coordinated pilot test work plan may include multiple pilot tests for one or more representative reservoirs and encompass multiple impaired reservoirs in which pilot tests are not conducted. A coordinated pilot test work plan must describe the finalized criteria to determine that each “representative reservoir" is sufficiently similar to other reservoirs, and list the similar reservoirs associated with each “representative reservoir.”

A coordinated pilot test work plan should be designed to evaluate one or more reasonable and practicable management practices that could be implemented within each of the impaired reservoirs to attain all TMDL targets applicable to each reservoir. Additionally, a work plan must provide detailed descriptions of the following:

(1) Each of the reservoir owners and operators’ impaired reservoirs, pilot test impaired and non-assessed reservoirs, and if applicable, associated studies in non-impaired reservoirs;

(2) Evaluation of each of the reservoir water chemistry management actions listed in section 9.8.1 for applicability in each impaired reservoir and any non-assessed reservoir proposed for pilot tests; and for each impaired reservoir justification for why any management practice is or is not relevant to or is infeasible to pilot test;

(3) Which specific actions are proposed to be pilot tested in which specific impaired and non-assessed reservoirs, how pilot test reservoirs will be monitored and evaluated, and what associated studies will be conducted in which non-impaired reservoirs;

(4) How the water chemistry pilot tests will be conducted, i.e., design and permitting; baseline monitoring; equipment installation; pilot test procedures; equipment operations and maintenance; and monitoring effectiveness in reducing in-reservoir methylation and fish methylmercury levels;

(5) If applicable, how fisheries management pilot tests will be coordinated with fisheries managers and how they will be conducted, i.e., design and permitting; baseline monitoring; equipment installation; pilot test procedures; equipment operations and maintenance; and monitoring effectiveness in reducing bioaccumulation and fish methylmercury levels; and

(6) Time schedule(s).

Additional measures may be included in pilot tests as directed by the Technical Review Committee or at the discretion of reservoir owners and operators to ensure technical adequacy, scientific rigor, or for efficiency. The work plans must also explain any additional measures in detail. Additional measures may include, but are not limited to, the following:

(1) Control reservoirs and associated studies in impaired and non-assessed reservoirs;

(2) Characterize inorganic mercury or methylmercury in reservoir inflows, and compare to in-reservoir mercury conditions; and

(3) How, if applicable, methylmercury production and bioaccumulation in reservoirs will be determined and quantified.

See section 9.8.6 regarding monitoring effectiveness in reducing fish methylmercury levels.

Individual pilot test work plans

Separate work plans must be developed for each impaired reservoir that is not part of a coordinated work plan. Each work plan must be designed to evaluate one or more reasonable and practicable management practices that could be implemented within the impaired reservoir to attain all applicable TMDL targets. Each work plan must provide detailed descriptions of the following:

(1) Impaired reservoir and if applicable, associated studies in non-impaired reservoirs;

(2) Evaluation of each of the reservoir water chemistry management actions listed in section 9.8.1 for application in the impaired reservoir, and justification for why any management practice is or is not relevant to or is infeasible to pilot test;

(3) Which specific actions are proposed to be pilot tested, how pilot test reservoir will be monitored and evaluated, and if applicable what associated studies will be conducted in which non-impaired reservoirs; and

(4) How the water chemistry pilot tests will be conducted, i.e., design and permitting; baseline monitoring; equipment installation; pilot test procedures; equipment operations and maintenance; and monitoring effectiveness in reducing in-reservoir methylation and fish methylmercury levels;

(5) If applicable, how fisheries management pilot tests will be coordinated with fisheries managers and how they will be conducted, i.e., design and permitting; baseline monitoring; equipment installation; pilot test procedures; equipment operations and maintenance; and monitoring effectiveness in reducing bioaccumulation and fish methylmercury levels; and

(6) Time schedule(s).

Additional measures may be included in pilot tests as directed by the Technical Review Committee or at the discretion of reservoir owners and operators to ensure technical adequacy, scientific rigor, or for efficiency. The work plans must also explain any additional measures in detail. Additional measures may include, but are not limited to, the following:

(1) Control reservoirs and associated studies in impaired and non-assessed reservoirs;

(2) Characterize inorganic mercury or methylmercury in reservoir inflows, and compare to in-reservoir mercury conditions;

(3) How, if applicable, methylmercury production and bioaccumulation in reservoirs will be determined and quantified.

See section 9.8.6 regarding monitoring effectiveness in reducing fish methylmercury levels.

Pilot test progress reports

Pilot test progress reports are needed to keep the Water Boards and interested parties informed of progress and challenges to progress that require a revision to the work plan. Accordingly, pilot test progress reports should describe the progress made to date on the pilot tested management practice(s), any preliminary findings or results, and any recommendations to revise pilot test work plans.

Pilot test draft and final reports

Pilot test draft reports must describe results of the pilot test(s) and recommendations for long-term reservoir water chemistry (and if applicable fisheries management, see section 9.9) practices to achieve all applicable targets in each impaired reservoir. Draft reports must be submitted for review to the Technical Review Committee and to the Water Boards. Owners and operators must revise these reports to account for the Technical Review Committee's conclusions and recommendations and the Water Boards direction prior to submitting the final pilot test reports to the Water Board. The final pilot test reports must assess effectiveness in reducing fish methylmercury levels, economic costs, potential public and environmental benefits of lower fish methylmercury levels, and potential negative impacts of long-term operations of mercury controls.

Long-term reservoir management strategy report

The long-term reservoir management strategy report should describe on-going and one-time in-reservoir management actions to attain all TMDL targets applicable to each reservoir. On-going management actions may include year-round, infrequent, or seasonal actions to manage water chemistry, or other repeated actions. An example of a seasonal or year-round action is oxygenation to reduce methylation. An example of an infrequent action may be to remove vegetation along exposed shorelines during extended drawdown, if vegetation removal would likely reduce methylation upon reservoir re-filling. An example of a one-time management action is removal of mercury-contaminated sediments along exposed shorelines during extended drawdown.

The long-term reservoir management strategy report should account for statistically significant differences in methylmercury production and fish methylmercury concentrations between locations within a reservoir, and therefore why and how recommended management actions are focused to limited areas or will be conducted throughout the impaired reservoir.

The next section provides a schedule to provide adequate time for pilot tests and support timely program review.

9.8.5 Schedule for Phase I Pilot Tests

Pilot tests and final pilot test reports should be completed within the ten year duration of Phase 1, so that the results can be evaluated during program review (see section 9.13.2).

Notice, Coordination, and Technical Review Committee

Within six months of the effective date of the Mercury Reservoir Provisions, the Water Boards plan to issue an order (i.e., California Water Code section 13267 technical report requirement) to reservoir owners and operators to inform them of their responsibilities to conduct Phase 1 pilot tests described in sections 9.8 and 9.9, preferably in one coordinated statewide effort. The order will be addressed to owners and operators of non-FERC-licensed Phase 1 impaired reservoirs.

The recipients must respond to the order in a timely manner, i.e., within three months, to inform the Water Boards whether they are proceeding individually or planning to join a coordinated approach. The coordinating parties are advised to submit their draft agreement (see section 9.8.3) for review and approval by the Executive Director of the State Water Board to ensure that the draft satisfies all requirements before it is signed by the participants. The signed agreement must be submitted to the Water Boards within in a timely manner, i.e., within nine months of issuance of the order.

The recipients will also be required to convene and fund the Technical Review Committee (see section 9.8.8) in a timely manner, i.e., within 12 months of issuance of the order.

Pilot test work plans

The reservoir owners and operators should submit the coordinated and individual draft pilot test work plan(s) as soon as possible but no later than 15 months after issuance of the order, for review by the Technical Review Committee and the Water Boards. The reservoir owners and operators must revise the pilot test work plan(s) in response to conclusions and recommendations from the Technical Review Committee and comments from the Water Boards.

The reservoir owners and operators must submit the final pilot test work plan(s) to the Water Boards for approval as soon as possible but no later than two years after issuance of the order.

Conduct pilot tests

The reservoir owners and operators must begin conducting the reservoir water chemistry (and if applicable fisheries management, see section 9.9) pilot tests within six months of Water Boards approval of final pilot test work plan(s).

Pilot test progress and final reports and long-term reservoir management strategy reports

Reservoir owners and operators must submit a progress report(s) on their pilot test(s) to the Water Boards every year to ensure timely tracking of pilot test(s) and early identification of challenges and delays.

The Mercury Reservoir Provisions require that by ten years after the effective date, reservoir owners and operators must submit to the Technical Review Committee and Water Boards a final pilot test report(s). Previously, however, reservoir owners and operators must have submitted to the Technical Review Committee and Water Boards a draft pilot test report(s).To support meeting the final report due date, reservoir owners and operators are advised to submit a draft pilot test report(s) by no later than eight and one-half years after the effective date to both the Technical Review Committee and Water Boards. This schedule would allow six months to receive Technical Review Committee’s conclusions and recommendations and comments from the Water Boards, and finalize the pilot test report(s) by the due date.

By ten years after the effective date, reservoir owners and operators must submit to the Technical Review Committee and Water Boards a final long-term reservoir management strategy report for each of their impaired reservoirs. Previously, however, reservoir owners and operators must have submitted to the Technical Review Committee and Water Boards draft reports. To support meeting the final strategy report due date, reservoir owners and operators are advised to develop draft reports by no later than nine and one-half years after the effective date to both the Technical Review Committee and Water Boards. This schedule would allow six months to receive Technical Review Committee’s conclusions and recommendations and comments from the Water Boards, and finalize the long-term reservoir management strategy reports by the due date.

Duration of pilot tests

This schedule allows for several years for pilot testing over the course of the ten years duration of Phase 1. The earliest date for Water Board approval of pilot test work plans is 36 months after the effective date of the Mercury Reservoir Provisions Accordingly, pilot tests will begin in the fourth year, and at the latest they will conclude in the eighth year, which allows for reporting in the ninth and tenth years. This schedule provides as many as five years for pilot tests (years four through eight subsequent to effective date), and two years to develop and finalize the pilot test report(s) and long-term reservoir management strategy reports. This timeline allows for both the Water Boards and reservoir owners and operators to consult with the Technical Review Committee on how best to finalize each pilot test report and long-term reservoir management strategy report. After receipt of the final pilot test reports and long-term reservoir management strategy reports, and after Water Boards approve the long-term reservoir management strategy reports, the Water Boards will undertake the program review described in section 9.13.2.

The next section (9.8.6) describes efficient ways to monitor fish methylmercury levels during pilot tests, to be considered in pilot test work plans. The subsequent section (9.8.7) describes long-term implementation of water chemistry management actions (and if applicable, fisheries management actions, see section 9.9).

9.8.6 Assessing Progress in Reducing Fish Methylmercury Levels

Methylmercury levels in sport fish are not a direct measure of recent implementation actions because sport fish are several years old and have bioaccumulated methylmercury over their lives. For initial measures of progress, rather than sampling sport fish, staff recommends that young fish be sampled because they have accumulated methylmercury for a short time period and reflect recent methylmercury exposure, which means there are fewer confounding factors that contribute to methylmercury levels in older sport fish compared to younger fish.

Fish selection (age and size)

Pilot test work plans should consider use of biosentinel fish rather than sport fish to determine whether pilot tests statistically significantly reduce fish methylmercury levels. Biosentinel fish are young (up to 1-year-old) prey fish with high site fidelity. The rationale for biosentinels is they provide more precise measurements of bioaccumulation than sport fish, because biosentinels accumulate all their methylmercury during the test period whereas sport fish have accumulated methylmercury over several years and not only during the test period. In any case, it is expected that baseline fish data sets will need to be collected in pilot test and if applicable also in control reservoirs. The work plan should consider collection of additional seasonal and inter-annual fish baseline data sets to help with interpretation of pilot test results.

Biosentinels: Young fish (<1 year)

Some desirable qualities of biosentinels used to assess progress include that they (a) are plentiful so sampling does not cause appreciable damage to the ecosystem, (b) are easy and inexpensive to collect, measure, and interpret, and (c) have high site fidelity so they provide relevant spatial information.

One such option, which provides more precision in measuring changes from one year to the next than sport fish, is small fish in a limited size range, up to about one year of age. These young fish provide more precise indicators of changes because they have only bioaccumulated methylmercury over one year or less. Fish corresponding to the size specified in the prey fish objective (50 to 150 mm in total length) meet these criteria. However, biosentinel prey fish need not exactly match the fish size range of targets. Instead, a smaller size range of prey fish and a single species could also be justified, e.g., largemouth bass 80 to 120 mm. The proposed biosentinel fish would need to be the same age and species for the different sampling events to allow direct year-to-year comparisons. Proposals for biosentinels that do not correspond exactly to the targets must be reviewed by the Technical Review Committee and if warranted, subsequently considered by the Water Board.

Note that currently, nearly all reservoir fish methylmercury data are for sport fish. Consequently, in nearly every reservoir it will be necessary to collect a baseline data set of young fish, i.e., a measure of “before” conditions, to use to assess progress. This is applicable both in reservoirs selected for pilot tests as well as for future evaluations of the effectiveness of long term reservoir management actions.

During pilot tests, after a clear trend of lower fish methylmercury levels emerges in young fish, then it may be cost-effective and informative to next sample a small number of standardized-size sport fish, as described in the following section. However, if the sport fish target does not apply to the subject reservoir, then prey fish sampling should commence in accordance with procedures described in Chapter 10.

Standardized-size sport fish

For impaired reservoirs for which the sport fish target applies, another assessment approach is the use of standardized-size sport fish. “Standardized-size fish” is a statistical calculation of fish methylmercury levels at a selected size, based on a data set that includes fish that range in size above and below the selected standardized size. For example, 350 mm standardized-size black bass are already widely used, and 250 gram standardized-size trout have been used (Slotton et al. 1997).

An advantage of the 350 mm standardized-size black bass is that a baseline data set is already available for many reservoirs (see Chapter 3). A second advantage is that 350 mm standardized is equivalent to average methylmercury concentration (see Chapter 5).

At first, sampling could focus on standardized-size fish. It may be cost-effective and informative to collect relatively small numbers of sport fish (i.e., about 10) for individual (not composite) laboratory analysis and calculation of methylmercury level in standardized-size sport fish. before collecting relatively large sample sets (i.e., about 30) of sport fish. If the data indicate standardized-size sport fish methylmercury levels still exceed the proposed sport fish target, then more implementation actions should be undertaken.

Once the data indicate standardized-size sport fish methylmercury levels are at or below the proposed sport fish target, then it would be timely to collect sport fish to measure average (rather than standardized) sport fish methylmercury to demonstrate attainment of the target (see Chapter 10 and its appendices for sampling and data analysis). (Also see Chapter 10 and its appendices regarding the number of fish to be collected, which should be informed by the variance in fish methylmercury levels in previous data sets and the size of the reservoir, but no fewer than 9 fish.) Additionally, if either the CA least tern or prey fish targets apply to the subject reservoir, then prey fish sampling must also commence in accordance with procedures described in Chapter 10.

Measure all targets

In all cases, assessment of compliance with TMDL targets requires repeated sampling of fish of sizes that correspond to applicable targets and in accordance with procedures described in Chapter 10.

9.8.7 Long-term Implementation

Long-term reservoir management strategy reports are the final Phase 1 requirements for reservoir owners and operators. Implementation of water chemistry management actions in these strategy reports will be required only after the State Water Board performs a program review of the Mercury Reservoir Provisions and initiates Phase 2 of implementation. Initiating Phase 2 requires a future amendment to the Water Quality Control Plan for Inland Surface Waters, Enclosed Bays, and Estuaries of California, as described in section 9.13.3.

9.8.8 Technical Review Committee

The Water Boards order (see section 9.8.2) compelling pilot tests will require reservoir owners and operators to form and fund a third-party, independent Technical Review Committee. The purpose of this statewide Technical Review Committee is to assist in the selection of representative reservoirs, review individual and coordinated plans and reports, provide advice to the reservoir owners and operators (and fisheries managers), and provide recommendations to the Water Boards on the adequacy, scientific merit, and results of the pilot tests. One Technical Review Committee will encompass both water chemistry and fisheries management.

Technical Review Committee members must be independent from the entities convening the committee and have technical expertise relevant to the pilot tests. Independent means having no financial interest with the owners and operators of impaired reservoirs or in any reservoir owned by the owners and operators, or authority over the reservoir operations. The Technical Review Committee should have no fewer than three members, each of whom has highly-regarded expertise in at least one of the following areas: (1) reservoir operations, (2) mercury cycling in lakes and reservoirs, and (3) fisheries management. One member should serve as the chair of the committee. The committee should operate by consensus, but if necessary, the chair will make final rulings.

Technical Review Committee members must be pre-approved by the Executive Director of the State Water Board. Moreover, the final proposed membership of the Technical Review Committee is planned to be subject to review and approval of the State Water Board. The owners and operators may elect to involve a third party to coordinate, convene, and manage the Technical Review Committee.

The Technical Review Committee must be convened and membership approved no later than 12 months after receipt of Water Boards order compelling pilot tests. Owners and operators are required to provide all pilot test work plans, final reports, and long-term reservoir management strategy reports to the Technical Review Committee for its review. Owners and operators must revise these plans and reports to account for the Technical Review Committee’s conclusions and recommendations prior to submitting them to the Water Board.

The Technical Review Committee should meet approximately 60 days prior to due dates for submittal to the Water Boards of the pilot test work plans, final reports, and the long-term management strategy reports, and may have additional meetings. The meetings should include a review and public discussion of the Technical Review Committee members' advice to the owners and operators and to the Water Boards on the adequacy and scientific merit of the submittals and advice on implementation of pilot tests and long-term strategies. The Technical Review Committee will provide reports to the Water Boards of their review, conclusions, and recommendations.

9.8.9 Credit for Early Actions

The Water Boards plan to provide credit for early actions—specifically, credit for pilot tests initiated or completed prior to the State Water Board's adoption of the Mercury Reservoir Provisions. To encourage early actions, the Water Boards provided funds for mercury monitoring for early pilot tests, and informed owners and operators of over 150 reservoirs about these funds for monitoring (150 reservoirs preliminarily identified as mercury-impaired for Phase 1). Some entities have taken advantage of these funds for monitoring. For example, the City of San Diego took advantage of these funds for a pilot test of oxygenation in Lake Hodges.

Credit from the Water Boards would mean that reservoir owners and operators would not need to repeat pilot tests during Phase 1 in reservoirs in which pilot tests were initiated or completed prior to the State Water Board's adoption of the Mercury Reservoir Provisions. Credit is specific to individual owner or operator that completed the work and may not be shared or assigned to another owner or operator to satisfy a coordinated approach.

9.9 Fisheries Management Actions for Mercury-Impaired Reservoirs

This section describes the implementation plan to address fisheries in mercury-impaired reservoirs. This section supports the actions directed by Mercury Reservoir Provisions Chapter IV.F and recommended by Chapter V.B. during Phase 1 for fisheries management.

A related topic, reduction of human exposure to consumption of fish with elevated levels of methylmercury, including recommendations to the Department of Fish and Wildlife, is included in section 9.12. This implementation plan for fisheries is based on the analysis in Chapter 7 and Appendix A.

9.9.1 Phase 1 Actions for Fisheries Management

The Mercury Reservoir Provisions direct that the actions in Phase 1 are to complete pilot tests of fisheries management practices to determine whether they reduce methylmercury bioaccumulation. Reservoirs that are part of hydropower projects licensed by the Federal Energy Regulatory Commission ("FERC-licensed") would be excluded from mercury pilot test requirements in Phase 1 (see section 9.9.2).

As with the reservoir water chemistry pilot tests, the Water Boards prefer multi-party collaborative and targeted efforts between the responsible parties for Phase 1 pilot tests (see section 9.9.3).

As with the reservoir water chemistry pilot tests, the goal of the pilot tests is to determine whether management actions reduce fish methylmercury levels. A successful pilot test is one that allows determination of whether a management action is successful <u>or not</u> in achieving reductions in fish methylmercury levels.

Phase 1 pilot tests

Phase 1 pilot tests of different fisheries management practices are needed to determine actions to meet the goal of reducing methylmercury levels in fish consumed by human and wildlife. Phase 1 actions have the following components: (a) include studies to characterize methylmercury bioaccumulation in reservoirs; (b) include pilot tests of fisheries management practices to reduce methylmercury bioaccumulation; (c) notify and request approval from the entity or entities that either directly stock and/or are responsible for stocking or otherwise responsible for fisheries management in the reservoir; and (d) consultation with the California Department of Fish and Wildlife regarding fisheries management practices to reduce bioaccumulation. These pilot tests should follow the activities and schedules described previously for reservoir water chemistry management in section 9.8.5.

The Mercury Reservoir Provisions require reservoir owners and operators to conduct reservoir pilot tests to develop and evaluate a range of reasonable and practicable management practices that could be implemented within each of their reservoir(s) to attain all TMDL targets applicable to each of their reservoir(s).

The scope of fisheries management actions to be evaluated could include at least the following (from Chapter 4 and Appendix A):

- Nutrient management such as minimal additions of nitrogen or phosphorus (including from natural sources such as restoring historical salmon runs) to slightly increase chlorophyll-a concentrations in oligotrophic reservoirs for two benefits. The first benefit is from reducing the concentration of methylmercury in algae, and hence lower methylmercury at the base of the food web. The second benefit is from providing more nutritious food at the base of the food web to increase fish growth rate and reduce fish methylmercury concentrations through somatic growth dilution.
- Intensive fishing to reduce fish populations so that there are more food resources for the remaining fish. This increases the growth rate in remaining fish, and reduces their methylmercury concentrations through somatic growth dilution.
- New or changes to fish stocking practices to increase the abundance of fish with lower methylmercury levels, such as by (a) stocking low-methylmercury prey fish for reservoir predator fish to consume, (b) stocking more or different species of sport fish, including lower trophic level sport fish, and/or (c) stocking large, old predator fish from hatcheries that supply low-methylmercury fish.
- Assess whether and how fish assemblages might be modified and managed to result in lower methylmercury levels in top predator fish.

(The scope of reservoir water chemistry management actions to be evaluated is described in section 9.8.)

Technical Review Committee

An independent, third-party Technical Review Committee should be convened to assure the fisheries managers, reservoir owners and operators, Water Boards, and concerned public that pilot tests are conducted with high scientific merit and address fisheries (and reservoir) operating constraints. One Technical Review Committee should be convened that encompasses both fisheries management and water chemistry for efficiency and effective communications (see section 9.9.7).

Technical adequacy of pilot tests

As with the reservoir water chemistry pilot tests, an important benefit of the Technical Review Committee is advice on scientific components of pilot test work plan such as baseline monitoring, monitoring pilot test effectiveness, and pilot test procedures. The Technical Review Committee's advice should improve the technical validity and efficiency of pilot tests.

Considerations for baseline and effectiveness monitoring are very similar to reservoir water chemistry, and so are not repeated here (see section 9.8.1). Similarly, considerations of control (i.e., "reference") reservoirs and associated studies are very similar to reservoir water chemistry, and so are not repeated here (see section 9.8.1).

Proposed Phase 1 pilot tests

Table 9.3 contains preliminary recommendations for pilot tests, associated studies, and control sites. Studies also could evaluate seasonal and inter-annual variation in fish methylmercury levels and food web characteristics, to help distinguish between effects of pilot tests and these temporal variations.

Pilot tests may also help with evaluating the feasibility of reducing methylmercury bioaccumulation more than the minimum needed to attain all TMDL targets applicable to each reservoir, as described in section 9.8.1.

Reducing methylmercury bioaccumulation to lower than the minimum to attain targets could provide an additional margin of safety or perhaps allow people to consume locally-caught fish at rates higher than 32 grams per day (one meal per week).

9.9.2 Responsible Parties and Regulatory Authority for Fisheries Management

Reservoir owners and operators are the responsible parties for pilot tests of fisheries management actions to reduce fish methylmercury levels. Reservoirs that are part of hydropower projects licensed by the Federal Energy Regulatory Commission ("FERC-licensed") are excluded from mercury pilot test requirements in Phase 1.

The Department of Fish and Wildlife (DFW) oversees fisheries management and regulations statewide. The Mercury Reservoir Provisions recommend that DFW coordinate with interested reservoir owners and operators on pilot tests. The Mercury Reservoir Provisions also recommend that DFW implement fisheries management actions (listed in Phase 1 pilot tests in previous section) in all reservoirs to reduce methylmercury levels in fish to the extent that those fisheries management actions do not conflict with programs DFW is authorized to implement. DFW's actions for water quality, including fish methylmercury levels, must comply with water quality control plans approved or adopted by the State Water Board unless otherwise directed or authorized by statute (Wat. Code, § 13247).

9.9.3 Coordinated Approach

The Water Boards prefer a coordinated approach (i.e., multi-party collaborative and targeted effort) for Phase 1 pilot tests including reservoir owners and operators and fisheries managers. To that end, the Mercury Reservoir Provisions require reservoir owners and operators who are not the sole party responsible for fish management in the reservoir to notify and request approval for fisheries pilot tests from the entity or entities that either directly stock and/or are responsible for stocking or otherwise responsible for fisheries management in the reservoir .

Representative reservoirs

A major advantage to a coordinated approach is that pilot tests could be conducted in fewer, targeted reservoirs rather than in all impaired reservoirs, for fisheries as well as for water chemistry (see section 9.8.3).

Coordinated approach

Key features of coordinated programs acceptable to the Water Boards are similar to those for reservoir water chemistry provided in section 9.8.3 and are the following:

- Preferably one statewide work plan that addresses pilot tests for both reservoir water chemistry and fisheries management, but up to three work plans for reservoir management and three work plans for fisheries management are acceptable.
- Reservoirs included in a coordinated approach must be representative of the reservoirs of those entities participating in the coordinated effort.

Pilot tests conducted in representative reservoirs must provide information to help answer management questions 1 and 2 in section 9.13.2. For example, some management questions are the following:

- Where is bioaccumulation occurring and what are the controlling factors?
- How do reservoir fish and food webs differ from one reservoir to another reservoir, and how should the Statewide Mercury Control Program for Reservoirs account for these differences?
- Are there localized, within-reservoir, bioaccumulation effects?

Mechanisms of coordination

The coordinated approach must be formalized with a binding agreement signed by all participants and submitted to the Water Boards, such as a Memorandum of Understanding. The agreement must contain at least the provisions listed in section 9.8.3.

9.9.4 Work Plans and Reports

As with reservoir water chemistry, the Mercury Reservoir Provisions require work plans and reports to support coordinated or individual pilot tests and long term reservoir management strategy reports. The Mercury Reservoir Provisions direct that the pilot tests and reporting have the same content as required for water chemistry pilot tests in section 9.8.4.

9.9.5 Schedule for Phase I Pilot Tests

As with reservoir water chemistry, fisheries management pilot tests and final pilot test reports must be completed within the ten-year duration of Phase 1, so that the results can be evaluated during program review (see section 9.13.2). The Mercury Reservoir Provisions direct that the pilot tests and reporting proceed on the same schedule as provided for water chemistry pilot tests in section 9.8.5. Additionally, within six months of the effective date of the Mercury Reservoir Provisions, the Water Boards plan to send a written recommendation to DFW to coordinate with interested reservoir owners and operators on the fisheries pilot tests.

Also, the time schedule has to accommodate permitting. For example, it will likely be necessary to obtain an individual or a general Waste Discharge Requirements or other permits from the Water Boards prior to additions of nutrients (e.g., nitrogen or phosphorus). It may be necessary to obtain written approval or permits from DFW prior to some pilot tests, such as pilot tests that involve changes to stocking or re-locating fish to another reservoir.

9.9.6 Long-term Implementation

Long-term reservoir management strategy reports are the final Phase 1 requirements for reservoir owners and operators. Implementation of fisheries management actions in these strategy reports will be required only after the State Water Board performs a program review of the Mercury Reservoir Provisions and initiates Phase 2 of implementation. Initiating Phase 2 requires a future amendment to the Water Quality Control Plan for Inland Surface Waters, Enclosed Bays, and Estuaries of California, as described in section 9.13.3.

9.9.7 Technical Review Committee

The need to establish and for fisheries manager to help fund a third-party, independent Technical Review Committee is the same as described for reservoir water chemistry (see section 9.8.8). One Technical Review Committee should encompass both water chemistry and fisheries management. Accordingly, the Technical Review Committee includes at least one member with expertise in fisheries management.

9.10 Dredging, Use, and Disposal of Mercury-Contaminated Sediments In or Upstream of Reservoirs (“Discharges from Dredge and Fill Activities”)

This section describes the implementation plan for dredging and earth-moving activities undertaken for purposes other than mercury remediation (cleanup) that may discharge mercury that originated from historical mines to any impaired, non-impaired, or non-assessed reservoir. This section supports the actions directed by Mercury Reservoir Provisions (Chapters III.A. and IV.F.) during Phase 1 for mercury from historical mines discharged from activities that disturb mercury-contaminated sediments.

This section describes the implementation plan for activities that disturb mercury-contaminated sediments (a) located downstream of a mine site and upstream of a mercury-impaired reservoir, or (b) located at or downstream of a mine site and upstream of or in any non-impaired or non-assessed reservoir. Note that sections 9.2 and 9.3 also address discharges of mercury from historical mines. In particular, section 9.2 addresses cleanup of mercury-contaminated mine sites located upstream of mercury-impaired reservoirs.

The purpose of addressing these activities is to (a) minimize discharges of mercury from dredging, use, and disposal of mercury-contaminated soils and sediments, and to (b) protect additional reservoirs from becoming mercury-impaired. This implementation plan for dredging is based on the analyses in Chapters 6 and 7 and staff's experience with dredging.

Herein, mining waste, soil, and/or sediments are collectively referred to as "sediments." Also herein, "upstream" of reservoirs means upstream of, adjacent to, or in reservoirs. Additionally herein, "activities" that disturb sediments refers to removing or moving sediments, i.e., dredging and earth moving. Examples of activities downstream of mine sites include, but are not limited to the following: dredging of sediments to deepen rivers or reservoirs; excavating sediments for bridge pier construction or repair; and placement of sediments for watercourse crossings. Examples of activities at mine sites include, but are not limited to, construction or maintenance of roads that intersect mining wastes.

Herein, plans or reports are described as being submitted for approval to the "Water Boards." In practice, as directed by the Mercury Reservoir Provisions, the plans or reports are submitted for approval to either the applicable Regional Water Board's executive officer or the State Water Board's executive director (depending on which board issues the dredging and use permits, see section 9.10.2).

9.10.1 Goals for Dredging, Use, and Disposal of Mercury-Contaminated Sediments

The goal for activities that disturb mercury-contaminated sediments is to minimize discharges of mercury to reservoirs by reasonable and feasible means.

The Water Boards plan to address proposed activities that disturb mercury-contaminated sediments upon receipt of permit applications, as described in the next section.

9.10.2 Regulatory Authority and Responsible Parties for Dredging, Use, and Disposal

The Water Boards plan to use its federal Clean Water Act section 401 authority, and as applicable its California Water Code authority, for activities that disturb mercury-contaminated sediments. The Water Boards issue "dredging and use permits" after receipt of applications for Clean Water Act section 401 water quality certifications and/or receipt of reports of waste discharge (Wat. Code, § 13260). Dredging and use permits may utilize either or both federal Clean Water Act section 401 authority or California Water Code authority for waste discharge requirements (Wat. Code, § 13263) or conditional waivers of waste discharge requirements (Wat. Code, § 13269).

Dredging and use permits will specify measures needed to minimize discharges of mercury directly to or to tributaries of reservoirs. Measures will likely address activity design, dredging, use, disposal, and monitoring. Design standards, for example, specify steepness of final slopes; moisture content and compaction of sediments disposed on site; and stormwater and erosion control measures. Dredging standards, for example, specify appropriate actions to control discharges of mercury-laden sediments during dredging and earth-moving activities, fill placement, construction with sediments, and disposal of sediments. Monitoring standards, for example, specify minimum monitoring and reporting during dredging, and after completion of dredging and earth-moving activities to confirm that erosion and stormwater controls are effective.

The parties responsible for activities that disturb mercury-contaminated sediments are the applicants for dredging and use permits. The next section describes one of the first actions that project applications should take, which is to characterize mercury concentration prior to design.

9.10.3 Characterization Plans Prior to Activities

Prior to disturbing sediments downstream from a mine site, information is needed to determine if the sediments are contaminated with mercury. Therefore, project applicants will need to characterize mercury concentration throughout the vertical and lateral extent of sediments likely to be disturbed prior to designing disturbance activities. Accordingly, project applicants should develop “Sediment Characterization Plans for Dredging, Use, or Disposal” and submit them for approval by the Water Boards.

Further, for dredging projects that disturb mercury-contaminated sediments, project applicants will need to develop “Site Characterization Plans for Dredging” to characterize sediment mercury concentration at both surface and the proposed dredge depth. Dredging projects where, after dredging, sediments exposed at the lowermost dredge depth would have a median total mercury concentration greater than the median total mercury concentration in surface sediments will need to take additional actions described in the next section (9.10.4). The “Site Characterization Plans for Dredging” will need approval by the Water Board Executive Officer.

The characterization plans must describe sampling and analysis procedures in detail and conform to the following directions. This section provides direction for characterizing mercury concentrations. Section 10.4 provides direction for field procedures and laboratory analytical methods. The resulting sediment total mercury concentrations are to be compared to the applicable load allocation in Table 8.1. Permits issued by the Water Boards will include requirements to minimize mercury discharges if mercury concentrations exceed applicable load allocations.

The quantities and locations of samples needed to adequately characterize mercury concentration of sediments depend on site-specific conditions such as distribution of mining wastes and location(s) of disturbance activities. Project applicants must explain their rationale for sample quantities and locations.

For mining waste and soil on the landscape and not in waters, the project applicant will need to characterize median total mercury concentration in fines, i.e., samples passing 62.5 micron sieve. Sieving may not be needed if mining waste and soil are shown to consist primarily of fines. The applicant should collect individual samples for mercury characterization from areas likely to have higher mercury concentrations to identify if there are any “hotspots” to be considered in the design or disposal. Additionally, the applicant should characterize overall median mercury concentration of mining waste and soil likely to be disturbed. If the sidewalls and bottom of an excavation will not be covered and instead be left exposed to precipitation or stormwater, the applicant should also collect samples for mercury characterization of the sidewalls and bottom.

For sediments adjacent to and in waters, the project applicant will need to characterize median total mercury concentration in (a) surface layer (0 – 1 cm depth) of sediments to be disturbed, (b) full depth of sediments to be disturbed, and (c) adjacent sediments to be left in place (i.e., sidewalls and bottom). The applicant should characterize median mercury concentration in fines, i.e., samples passing 62.5 micron sieve. Sieving may not be needed if sediments are shown to consist primarily of fines.

Moreover, an additional step is advised for elemental mercury, which is likely to be present at mercury, gold, and silver ore processing locations. Sampling and excavation may disturb elemental mercury, if it is present. Allowing samples or newly exposed surfaces (exposed from excavation or dredging) to sit undisturbed for a day is likely to provide sufficient time for elemental mercury droplets to coalesce on the surface; droplets that are visible to the naked eye. Therefore, field personnel should allow samples and the excavated area to sit undisturbed for at least one day and then inspect all samples and site conditions for visible elemental mercury. If elemental mercury was observed, then excavation should extend to depths and widths that ensure removal of all visible elemental mercury.

The next section describes how mercury characterization should be considered in designs for dredging.

9.10.4 Dredging of Mercury-Contaminated Sediments

Prior to commencing activities, project applicants must submit for approval by the Water Boards a dredging work plan that includes designs for dredging. Designs for dredging should consider the following factors: (1) extent of dredging with respect to sediment mercury concentrations; (2) erosion or scour potential when dredging complete; (3) management of discharges during dredging or from temporary stockpiles; and (4) re-use or disposal sites. Project applicants cannot commence activities before they receive written approval from the Water Board Executive Officer for dredging designs.

Factor 1: Dredging should be deeper and wider than location of samples with visible (to the naked eye) elemental mercury. Sediments require cleanup if the sidewalls and bottom remaining after dredging has median mercury concentrations exceeding the median mercury concentration in surface sediments before dredging. A number of means may accomplish cleanup. Means of cleanup include but are not limited to the following: (a) excavating until reaching sediments that do not exceed the load allocation; (b) further excavating contaminated sediments and replacing them with clean fill or other materials that are free from contaminants;

or (c) treatments to ensure that contaminated sidewalls and bottom will not be susceptible to erosion or scour.

However, in some cases it may not be practical to dredge to depths at which mercury concentrations are no greater than surface sediments before dredging or otherwise remediate elevated mercury concentrations. This is likely where the surface layer is made up of recently deposited sediments and its median mercury concentration is greater than the applicable load allocation. It is also likely if mercury from historical mining has accumulated to great depths. Special demonstration is needed if the mercury concentration in sediments planned to be exposed in sidewalls and at the bottom is greater than median mercury concentration in the pre-dredge surface. In this case, the project proponents should demonstrate that the higher mercury concentration in the newly exposed sidewalls and bottom is short term (i.e., less than one year) because new sediments from upstream with lower mercury concentration will accumulate and cover the more contaminated sediments

Factor 2: Designs for dredging sediments from creek floodplains, banks, or channels, or from reservoirs should provide long term stable configurations with minimal erosion and scour. These designs should include grading of the channel after dredging so that both upstream and downstream transitions between the existing channels to the dredged areas are smooth and continuous. Smooth transitions ensure that dredging will not construct a "wall" of sediment or other blockage that could erode or cause erosion once flows are restored.

Designs for earthmoving on the landscape should provide long term stormwater and precipitation controls to minimize erosion. (See also design considerations to minimize erosion in section 9.2.4, *Implementation (Cleanup) Actions* and Appendix I.)

Factor 3: All dredging activities should be designed to minimize releases of mercury and sediments into the water column during dredging operations. Designs for mercury are likely to be similar to designs to minimize turbidity and suspended sediments.

Runoff (water and sediment) or decant water from dredged sediments should not contact waters of the State. The dredged sediments may be stockpiled onsite so that it can be loaded into trucks for offsite disposal within a reasonably short number of calendar days of the completion of the active work. Onsite stockpiled sediments should be fully contained to prevent any wind or water transport. The dredged sediments may also be temporarily stockpiled at an offsite location. Offsite stockpiles should be covered and surrounded with perimeter sediment control BMPs to ensure that dredged sediments remain stable.

Factor 4: Re-use or disposal sites are described in the next two sections.

9.10.5 Use of Mercury-Contaminated Sediments in Construction

Prior to using mercury-contaminated sediments in construction, project applicants must submit for approval by the Water Boards designs and plans for use of dredged sediments. Mercury-contaminated sediments obtained from dredging activities may be used in construction provided they do not contain visible elemental mercury. Additionally, sediments with median mercury concentration in fines equal to or that exceed the applicable load allocation may be used in construction with appropriate safeguards described in this section that prevent them from re-entering surface waters. Project applicants cannot commence activities before they receive written approval from the Water Board Executive Officer of the designs and plans for use of dredged sediments.

Dredged sediments typically require drying out to reduce water content before they are used in construction and sometimes prior to disposal. Designs for sediment drying areas should include measures to route stormwater overland flow away from the drying area. Stormwater and other liquid discharges from the drying area should be collected and routed to swales or sediment detention basins or managed in other effective manners to minimize discharges of mercury. Plans to minimize mercury discharges from sediment drying are subject to prior review and approval by the Executive Officer of the applicable Regional Water Board.

Depending on the threat to water quality, site-specific design requirements will be included in Water Board orders or permits described in section 9.10.2. These design requirements will ensure that the sediments are adequately protected from erosion into surface waters. Appropriate designs will vary from simple erosion control actions to specifying depth and compaction of soil cover to be placed over the sediments.

Hazardous waste requirements must be considered in plans for use of dredged sediments, if applicable. Dredged sediments with median mercury concentration greater than the hazardous waste limit (20 mg/kg, wet weight; from California Code of Regulations, title 22, section 66261.24, Total Threshold Limit Concentration value) should also be evaluated for soluble mercury and acid-generating potential. Site-specific design requirements should account for applicable waste containment requirements in Title 27 of the California Code of Regulations.

9.10.6 Disposal of Mercury-Contaminated Sediments

Prior to commencing activities, project applicants must submit for approval by the Water Boards designs and plans for on-site and off-site disposal of dredged sediments, if applicable. Designs are not required for disposal at a permitted municipal or hazardous waste landfill. On-site or nearby off-site disposal of mercury-contaminated sediments may be appropriate for most activities. Off-site disposal at solid or hazardous waste landfills is unlikely to be reasonable or feasible for most activities due to monetary and environmental costs from long haul distances.

Implementation actions for on-site or nearby off-site disposal vary from simpler erosion control actions to complex landfill construction depending on site-specific conditions, and are the same as provided for mine sites (section 9.2.4). Project applicants cannot commence activities before they receive written approval from the Water Board Executive Officer of the on-site or nearby off-site disposal plan.

9.10.7 Maintenance and Monitoring Plan

Prior to commencing activities, project applicants must submit for approval by the Water Boards a maintenance and monitoring plan that describes measures they will take to minimize releases of sediments during and after undertaking activities that disturb mercury-contaminated sediments. Minimizing releases of mercury-contaminated sediments will ensure that discharge of mercury is minimized. Project applicants cannot commence activities before they receive written approval from the Water Board Executive Officer of the maintenance and monitoring plan.

During-activity and post-activity maintenance, monitoring, and reporting for dredging (including on-site disposal) are needed to ensure that the measures to minimize scour and erosion and discharge controls continue to be effective. After completion of the activities, project applicants should submit annual reports for no less than two years to document compliance with the approved maintenance and monitoring plan. (See section 9.2.4 for additional details on maintenance, monitoring, and reporting.)

9.11 New Reservoirs

This section provides the implementation plan to address the potential for elevated fish methylmercury levels in reservoirs constructed after the effective date of the Mercury Reservoir Provisions ("new reservoirs"). This section supports the actions directed by Mercury Reservoir Provisions Chapter IV.F during Phase 1 for new reservoirs.

This implementation plan for new reservoirs is based on the literature review in Chapter 4.

Goals for new reservoirs

The goal with these actions is to ensure that new reservoirs have and maintain low fish methylmercury levels that attain the mercury objectives. In this way, the Statewide Mercury Control Program for Reservoirs aims to prevent mercury problems in new reservoirs.

Regulatory authority and responsible parties for new reservoirs

Prior to the construction of the impoundment structure for a new reservoir, the State or applicable Regional Water Board will include requirements or conditions in a California Water Code water right order, a federal Clean Water Act section 401 certification, or other appropriate order issued to the reservoir owner or operator.

Implementation actions for new reservoirs

Actions should be taken to control fish methylmercury levels in new reservoirs, because fish methylmercury levels typically increase between 2- and 7-fold after initial filling of reservoirs (i.e., flooding of terrestrial ecosystems; see Chapter 4). Peak fish methylmercury levels typically occur in 5 –15 years, but elevated levels can persist for as long as 35 years.

Actions that might prevent such high peaks or shorten the duration of elevated fish methylmercury levels should be included as conditions or requirements in Water Board permits or orders. The mercury-related permit conditions or requirements should include the following, on a site-specific basis:

- If reservoir is sited in a watershed with historical mines, (a) cleanup actively eroding mine sites and associated downstream mining waste located upstream of the reservoir to minimize discharges of mercury from historical mining, and (b) conduct comprehensive soil mercury monitoring of area to be inundated and cap or remove mercury-contaminated soils before flooding.

- Conduct controlled burns or other vegetation removal activities before filling a reservoir for the first time to minimize methylmercury production.
- Operational plans for new reservoirs should include active reservoir water chemistry and fisheries management to prevent or reduce methylmercury production and subsequent bioaccumulation by means proven feasible and effective by pilot tests undertaken in other reservoirs (see sections 9.8 and 9.9) and other relevant information. The operational plans should also include ongoing monitoring including aqueous and fish tissue methylmercury to assess the effectiveness of the control actions.
- Additionally, not stocking high trophic level species such as brown trout and bass will help to keep methylmercury bioaccumulation low.

Also, site selection may help to keep fish methylmercury levels low. Where possible, siting new reservoirs in watersheds that have (a) few or no historical mercury, gold, or silver mines, and (b) few or no mercury mineralized zones or other naturally mercury enriched areas will help to keep mercury inputs low.

9.12 Exposure Reduction Activities to Protect Human Health

This section supports recommendations for exposure reduction during Phase 1 in the Mercury Reservoir Provisions Chapter V.A. and V.B.

The purpose of these recommendations is to protect human health while methylmercury and inorganic mercury source reductions are occurring. Reductions in sources will take time, in some cases a long time. Subsequent reductions in fish methylmercury levels will also take time. Human consumers of reservoir fish will continue to be exposed to risks from methylmercury unless exposure reductions activities are undertaken during this time. These activities should be designed to protect people who eat mercury-contaminated fish from any reservoir, and particularly for consumption of fish from impaired reservoirs, by reducing their methylmercury exposure and its potential health risks. Any exposure reduction activities are not intended to replace timely reduction of inorganic mercury or methylmercury discharges to California's waters.

Recommendations for outreach activities regarding fish consumption advisories

The California Department of Public Health (Public Health) has authority and expertise to develop and implement a program to reduce human exposure to mercury-contaminated fish. Accordingly, Public Health is well-positioned to take action to inform the public about fish consumption advisories and consumption recommendations to protect human health. Public Health should ensure that appropriate information reaches all consumers, especially people and communities most likely to be affected by methylmercury in fish, such as subsistence fishers and their families.

The Office of Environmental Health Hazard Assessment (OEHHA) has authority and responsibility to issue fish consumption advisories. The Water Boards' Surface Water Ambient

Monitoring Program works with OEHHA to provide some fish data needed for consumption advisories. Accordingly, OEHHA is well-positioned to continue to provide timely, coordinated and consistent actions and activities for fish consumption advisories and other information for the public for both current and future water bodies identified as having fish with elevated levels of methylmercury.

Public Health and OEHHA are well-positioned to conduct public outreach and education activities. Accordingly, Public Health and OEHHA should coordinate with the reservoir owners and operators and other stakeholders to engage in public outreach and education activities regarding fish consumption advisories.

Reservoir owners and operators of mercury-impaired are the best-positioned entities to post fish consumption advisory signs at entrances to reservoirs. Accordingly, owners and operators of mercury-impaired reservoirs should post signs that contain, if available, a reservoir-specific advisory. Otherwise, owners and operators of mercury-impaired reservoirs should post the OEHHA Statewide Advisory for Eating Fish from California's Lakes and Reservoirs without Site-specific Advice.

Moreover, owners and operators of reservoirs with consumption advisories that advise either all people or sensitive population subgroups “do not eat” certain species should engage in additional public outreach and educational activities to discourage people from consuming those species of fish.

Recommendations for fisheries management to protect human health

The California Department of Fish and Wildlife (DFW) has authority to issue and enforce fishing licenses. Accordingly, DFW is well-positioned to regulate fish catch. DFW should change fish catch restrictions to reduce human consumption of larger, older fish with high methylmercury levels, e.g., implement “slot limits” that specify a safe size range of fish for consumption.

Additionally, DFW should change fishing regulations to protect human health where reservoir fish methylmercury levels are greater than the OEHHA threshold for ‘do not eat’ consumption advisories (currently 0.44 mg/kg on average). DFW could accomplish this protection by changing fishing regulations contained in title 14 of the California Code of Regulations (Division One) to limit the harvesting of fish of species and sizes known to have elevated levels of methylmercury. Then, DFW could ensure protection of human health by enforcing these harvest limits at reservoirs where data are available that show fish methylmercury levels exceed the OEHHA ‘do not eat’ threshold.

Lastly, DFW accomplishes significant outreach to and education of the public through its freshwater sport fishing regulations booklets, website, and other related efforts. Accordingly, DFW is well-positioned to take appropriate steps to notify fishing license holders and inform the public about safe and unsafe fish species for consumption. DFW should continue to provide fish consumption recommendations and advisories to fishing licensees and the public to protect public health.

Authorization to require posting of health warnings

If DFW, Public Health, OEHHA, and reservoir owners and operators fail to take appropriate fish consumption advisory outreach activities, the Water Boards are authorized to require others to post health warnings or to post the warnings themselves under appropriate circumstances. Under Water Code section 13304, the Water Boards can issue a Cleanup and Abatement Order directing anyone responsible for discharging wastes that have caused elevated fish methylmercury levels to post health warnings. Posting is a pollution or nuisance "abatement" activity authorized under section 13304. Under Water Code section 13304(b), the Water Boards may post warnings themselves under appropriate circumstances, for example, if there is no readily identifiable responsible party or urgent action is needed.

If the elevated fish methylmercury levels are not the result of waste discharges, then the Water Boards can use Water Code section 13225(d) and/or (g) to formally notify the local health officer of the health threat and officially request that the health officer post health warnings. Subsection (d) provides that the Regional Water Boards shall request federal, state, and local agencies to enforce their respective water quality control laws. Subsection (g) directs the Regional Water Boards to report any case of suspected contamination to the State Water Board and the appropriate local health officer. Further, if more assertive action is necessary, the Regional Water Boards can require the local health officer, under Water Code Section 13225(c), to investigate the problem and report back to the Regional Water Boards on the results of the investigation and actions that the health officer will take to protect the public.

The Regional Water Boards can coordinate the posting of health warnings under Water Code section 13225(a). This subsection requires the Regional Water Boards to "[c]oordinate with the state board and other regional boards, as well as other state agencies with responsibility for water quality, with respect to water quality control matters, including the prevention and abatement of water pollution and nuisance."

9.13 Adaptive Management and Program Review

Adaptive management is a systematic process that uses scientific information to help formulate management policies and practices. Additionally, adaptive management allows for continually improving those policies and practices by learning from the outcomes of research, field studies, pilot tests, implementation, and monitoring programs. Taking immediate actions based on currently available information allows California to make progress toward reducing reservoir fish methylmercury levels; simultaneously, we improve our understanding of mercury and methylmercury cycling through research and by observing how reservoirs respond to the immediate actions.

This implementation plan has adaptive management elements with the following features:

(1) Immediate actions commensurate with available data and information. The immediate actions are in the implementation plan (i.e., Phase 1 actions in sections 9.2 – 9.11) for each of the three factors (source control, and pilot tests for both reservoir management and fisheries management).

(2) Evaluation and reporting on status of immediate actions (i.e., pilot test progress and final reports) and progress toward achieving all TMDL targets applicable to each reservoir.

(3) Statement of management questions, associated scientific hypotheses, and framework and schedule for addressing management questions.

(4) Process for reviewing and incorporating into the Statewide Mercury Control Program for Reservoirs information obtained through studies and monitoring. This process is called "program review" and uses "focusing questions."

9.13.1 Reservoir Technical Review Committee

A Technical Review Committee is needed to review plans for and results of reservoir and fisheries pilot tests and associated studies, provide advice to reservoir owners and operators and fisheries managers, and provide recommendations to the Water Boards on the adequacy, scientific merit, and results of the studies. (Technical Review Committees are sometimes referred to as an "Expert Panel" or "Independent Science Panel.")

Sections 9.8.8 and 9.9.7 describe the requirement for reservoir owners and operators to convene and fund an independent Technical Review Committee that encompasses both water chemistry and fisheries management. (Section 9.8.8. also defines "independent," provides for appropriate technical expertise of committee members, and describes expectations for committee operations and work products.) The work of the Technical Review Committee is integral to adaptive management and program review. The Water Boards plan to consider Technical Review Committee's recommendations during program reviews and, as needed, at other times.

Examples of questions regarding pilot tests of water chemistry that could be put to the Technical Review Committee are the following:

- Did reservoir aqueous methylmercury levels decrease or other water chemistry factors change as expected as a result of the pilot test?
- If not, can this be explained, and if applicable, how should the pilot test be changed and continued?
- Did biosentinel fish methylmercury levels decrease as a result of the pilot test?

Examples of questions regarding pilot tests of fisheries management that could be put to the Technical Review Committee are the following:

- If the pilot test involved nutrient management, did reservoir chlorophyll-a levels increase, did the ratio of methylmercury to chlorophyll-a decrease, did other nutrient factors change as expected as a result of the pilot test, and did fish methylmercury levels decrease?

- If the pilot test involved intensive fishing, did the growth rate in remaining fish increase, and did their methylmercury concentration decrease, and were other effects from intensive fishing observed?

- If the pilot test involved changing stocking or changes in fish assemblages, did it cause expected reductions in fish methylmercury levels and were other effects from intensive fishing observed?

9.13.2 Program Review

The State Water Board plans to adapt the Statewide Mercury Control Program for Reservoirs to incorporate new and relevant scientific information such that effective and efficient actions can be taken to achieve program goals. This section supports the actions directed by Mercury Reservoir Provisions Chapter VI.

At a minimum, the State Water Board plans to review the Statewide Mercury Control Program for Reservoirs at the conclusion of Phase 1 to evaluate findings from early implementation actions, monitoring, special studies, and relevant scientific literature.

Issues for consideration in first program review

The first program review to be conducted at the conclusion of Phase 1 will, in accordance with Mercury Reservoir Provisions Chapter VI.B, commence with a public hearing pertaining to the issues it will consider during its Program Review. These issues will include at least the following:

(1) Consider reservoir pilot test results (i.e., data, reports, conclusions, and recommendations);

(2) Consider the Technical Review Committee’s advice and report (if report available);

(3) Consider focusing questions in section 9.13.2;

(4) Consider management questions in section 9.13.2;

(5) Review each long-term reservoir management strategy report to determine which, if any, strategies should be implemented during Phase 2 at each impaired reservoir;

(6) Consider whether any reservoirs determined after the effective date of the Mercury Reservoir Provisions to be impaired by mercury should be subject to the Mercury Reservoir Provisions pilot test or other requirements;

(7) Determine which reservoir management practices would apply to FERC-licensed reservoirs;

(8) Consider whether to require identification, cleanup, and control of lower priority (e.g., Tier 2 and Tier 3) mine sites or of mining waste downstream of mine sites; and

(9) Consider progress towards achieving each of the goals of the Statewide Mercury Control Program for Reservoirs.

The staff report may also consider potential public and environmental benefits and negative impacts resulting from implementation actions necessary to achieving all TMDL targets applicable to each reservoir. For example, the review may consider positive and negative impacts from mercury source controls and pilot tests on both habitat restoration, and fish consumption, and confirm that the program has no impact on either flood protection or water supply.

As appropriate, the staff report will include recommendations for changes to the Statewide Mercury Control Program for Reservoirs. Changes could be considered to targets, allocations, implementation actions, and schedules. Importantly, changes could be considered to adjust the approach from a statewide program to regional, watershed, local, or individual program, as appropriate.

The first program review will likely conclude with a State Water Board hearing to consider adopting modifications to the Mercury Reservoir Provisions to establish Phase 2 implementation actions.

Focusing questions for use in program review

At a minimum, the following focusing questions will be used to conduct the program review. Additional focusing questions will be developed in collaboration with stakeholders prior to each review.

(1) Assess results of reservoir and fisheries pilot tests:

  a. Are reservoir aqueous methylmercury levels decreasing and other bioaccumulation factors (e.g., chlorophyll-a) changing as expected? Are reservoir aqueous methylmercury concentrations, or the ratio of methylmercury to chlorophyll-a, useful to predict where or whether TMDL targets will be attained in Phase 2?

  b. Is the methylmercury allocation appropriate to meet targets? Should the methylmercury allocation be changed (e.g., non-detect at 0.005 ng/L; hypolimnion peak rather than annual geomean through water column; or different allocations for different types of reservoirs or geographic regions)? And if so, is there sufficient information to revise the methylmercury allocation?

  c. What reservoir and fisheries management practices were tested? Were these methods effective? Do they appear to be technically and economically feasible on a small or large scale in California? Do they have adverse environmental effects, and if so what can be done to avoid, minimize, or mitigate for these effects? Conversely, do they have positive environmental effects in addition to reducing reservoir fish methylmercury levels?

  d. Were pilot tests successful in reducing reservoir fish methylmercury levels? Are reservoir fish methylmercury levels decreasing as predicted in study work plans? Are reservoir fish methylmercury levels predicted to meet targets in Phase 2?

  e. What other reservoir and fisheries management practices should be considered for testing? Are the schedules and long-term reservoir management strategy reports proposed by responsible parties adequate to meet program goals?

f. If there has not been adequate progress in reducing fish or aqueous methylmercury levels, how might implementation actions or allocations be modified?

(2) Assess results of source reduction actions for mercury:

a. Are inorganic mercury source reductions being implemented as planned for Phase 1?

b. Are reservoir bottom sediment total mercury concentrations decreasing measurably? Are reservoir bottom sediment total mercury concentrations predicted to meet modern background levels in Phase 2? If it is unclear whether there is progress in controlling inorganic mercury sources and reducing reservoir bottom sediment total mercury concentrations, how should tracking, monitoring, and reporting efforts be modified to improve ability to detect trends?

c. Should a schedule be established for cleanup of Tier 2 and 3 mine sites (see section 9.2.1 for a description of tiers)?

d. If there has not been adequate progress in inorganic mercury source reduction, how might the implementation actions or allocations be modified?

e. Is it necessary to reduce sources of methylmercury as well as inorganic mercury to attain all TMDL targets applicable to each reservoir? If so, what methylmercury sources require reduction, and how and where might implementation actions be effective?

(3) Is the statewide approach effective and appropriate? If not, should the program be modified to a regional, watershed, local, or individual approach? And if so, what changes should be made to allocations and implementation actions, or other Statewide Mercury Control Program for Reservoirs elements?

(4) Is there new, reliable, and widely accepted scientific information that suggests modifications to linkage analysis, conceptual model, or controllable processes are appropriate? Or that modifications to targets, allocations, monitoring, or implementation actions are appropriate? If so, how should the Statewide Mercury Control Program for Reservoirs elements be modified?

a. For example, should the linkage analysis (see Chapter 5) be re-calculated with new, statewide data generated expressly for this purpose?

b. Should the margin of safety be revisited?

c. If data become available, should additional linkage analyses be conducted based on the prey fish and CA least tern targets?

Management questions

This section identifies management questions to improve understanding of mercury sources, fate, and effects in California reservoirs such that we can better manage the problem of elevated levels of methylmercury in fish. The management questions address the following topics:

1. Reservoir processes and effects, including reservoirs and fisheries management practices;
2. Source loads and implementation actions; and
3. TMDL targets.

The following discussion of each question includes, for example, brief descriptions of current hypotheses that may address the question, the proposed manner in which the question would be addressed (by whom and when), why the question is important, and how the information will be incorporated into the TMDL process.

Management Question 1a: Where is methylation occurring in the system and what are the controlling factors?

> This question must be addressed to develop reservoir management practices to suppress methylation and promote demethylation. Currently available information suggests methylation is occurring in reservoir bottom sediments from which it discharges into the water column. Oxygen depletion is a necessary condition for methylation, and methylation rates are lower at higher pH. Additionally, reservoirs produce some methylmercury in the metalimnion and epilimnion, and in contiguous wetlands and marshes. It is likely necessary to also identify controlling factors for methylation in these areas, as well as demethylation in the water column.
>
> This question can be addressed through a program of observation and controlled laboratory and field experiments. Studies are underway worldwide to answer this question, including in the Guadalupe River watershed in California. This question could be included in the reservoir studies for this control program, along with a survey of candidate chemical, biological, and physical controlling factors (i.e., reservoir management practices). These candidate controlling factors should then be further tested through controlled laboratory studies and field pilot tests.
>
> However, during the course of conducting pilot tests a lower detection limit for methylmercury in water may be needed to reliably measure environmental concentrations of methylmercury to help determine where and when methylation is occurring and which control measures are effective (see section 7.3.6).
>
> Sufficient data and information should be available to at least partially, if not completely, answer the management question posed above within ten years, by the end of Phase 1. Reservoir owners and operators are expected to incorporate this information in the "long-term reservoir management strategy report" described in section 9.8.4, the purpose of which is to direct reservoir management in Phase 2.

Management Question 1b: Where is bioaccumulation occurring and what are the controlling factors?

> This question must be addressed to develop both reservoir and fisheries management practices to reduce bioaccumulation. Currently available information suggests the base of the food web, pH, food chain length, and top predator species are key factors.

Abundant phytoplankton with low methylmercury concentrations (biodilution) results in fish with lower methylmercury levels. Increased pH and shorter food chain lengths also result in fish with lower methylmercury levels. Top predator species are often introduced species (bass and brown trout).

Like the first management question, this question can be addressed through a program of observation and controlled laboratory and field experiments. Studies are underway worldwide to answer this question, but Water Board staff is not aware of studies in California. This question should be included in each of the reservoir and fisheries studies for the Statewide Mercury Control Program for Reservoirs, along with a survey of candidate chemical, biological, and physical controlling factors (i.e., reservoir and fisheries management practices). These candidate controlling factors should then be further tested through controlled laboratory studies and field pilot tests.

Sufficient data and information should be available to at least partially, if not completely, answer the management question posed above within ten years, by the end of Phase 1. Reservoir owners and operators are expected to incorporate this information in the “long-term reservoir management strategy report” described in section 9.8.4, the purpose of which is to direct reservoir management in Phase 2. Similarly, fisheries managers are expected to incorporate this information in periodic updates of the “long-term reservoir management strategy report” they develop in compliance with the Statewide Mercury Control Program for Reservoirs.

Management Question 1c: How do reservoirs differ from one another, and how should the Statewide Mercury Control Program for Reservoirs account for these differences?

Answering this question will help to determine whether reservoir and fisheries management practices should be uniform or varying across California. It is hypothesized that reservoirs have varying duration and degrees of thermal stratification based on geography and use. Greater degrees of stratification require more mixing energy to overcome and contribute to longer periods of stratification. Longer stratified periods allow for greater oxygen depletion and methylmercury production in the hypolimnion.

Geography contributes to duration of stratification. Coast Ranges reservoirs, such as those in the Guadalupe River watershed, have a longer duration of stratification than reservoirs in other regions. This is primarily due to geographic factors such as Mediterranean climate and hence little storm-generated mixing in summer, and also due to these reservoirs filling with winter rains and slowly emptying through the rest of the year. In contrast, Sierra reservoirs fill both in winter and with spring snow melt, and are exposed to summer storms with wind and rain mixing energy, which results in increased reservoir mixing.

The purpose and use of a reservoir may also contribute to shorter duration and degree of stratification. Hydropower reservoirs likely have more frequent water level fluctuations and hence more mixing than solely water supply reservoirs; Folsom Lake and Lake Oroville are examples of hydropower reservoirs. Hydropower reservoirs are typically located in areas with high head (elevation gain) and plentiful water, such as in the Sierras, and consequently not in the Coast Ranges. Some are located in sequence, and the water level may fluctuate even more frequently in the lower reservoirs due to varying discharges from upstream that may fill and re-fill the lower reservoirs, for example Oxbow Reservoir. Filling may cause some mixing and thereby reduces stratification. A similar effect of frequent emptying and filling likely occurs in the “equalization” reservoirs for the large federal and state water projects, such as Lake Natoma downstream of Folsom Lake, and Thermalito Diversion Pool downstream of Lake Oroville, which are the last reservoirs in sequence before discharging to canals.

Reservoirs also vary in drawdown, that is seasonal fluctuation in water level, from year to year and from one reservoir to another. This implementation plan recognizes that most drawdown is necessary; after all, drawdown represents the water storage capacity that reservoirs are designed to provide. However, drawdown was shown in the Linkage Analysis (Chapter 5) to be correlated to fish methylmercury levels. Nonetheless, low water levels during drawdown may present opportunities for other reservoir management practices, such as excavating highly mercury-contaminated sediment or removing vegetation. These opportunities might or might not vary widely across California.

California reservoirs also vary in their primary productivity from crystal-clear waters (highly oligotrophic) to opaque, green waters (eutrophic). While low productivity is an asset for drinking water quality and results in less fouling in hydropower equipment and water conveyances, the slightly higher chlorophyll in nonetheless oligotrophic reservoirs is associated with biodilution and lower fish methylmercury levels.

This question can be addressed through a program of observation and controlled laboratory and field experiments. Studies are underway worldwide to answer this question, including by the Santa Clara Valley Water District in California. This question should be included in the reservoir studies for the Statewide Mercury Control Program for Reservoirs, along with a survey of candidate chemical, biological, and physical controlling factors (i.e., reservoir management practices). These candidate controlling factors should then be further tested for applicability across California through controlled laboratory studies and field pilot tests.

Water Board staff anticipates that sufficient data and information will be available to at least partially, if not completely, answer the management question posed above within ten years, by the end of Phase 1. Reservoir owners and operators are expected to incorporate this information in the “long-term reservoir management strategy” described in section 9.8.4, the purpose of which is to direct reservoir management in Phase 2. Additionally, the Water Boards plan to consider newly available information during program review, particularly to address focusing question 3 stated previously, which begins with, “Is the [uniform] statewide approach effective and appropriate?”

Management Question 2a: Are within-reservoir processes the most important factors for elevated fish methylmercury levels? Could external methylmercury sources also be important factors?

Answering this question will help to determine whether source reductions are also needed for external methylmercury sources to reservoirs. The conceptual model and linkage chapters evaluated many within-reservoir factors and external factors, but did not identify external methylmercury sources as significant contributors to fish methylmercury levels. However, this may reflect a limited data set. We hypothesize that external methylmercury sources could be important where urban runoff is the dominant source of supply water or where there is a relatively large upstream wetland.

This question can be addressed through a program of observation and controlled field experiments, such as food web studies that use carbon and nitrogen isotopes and aqueous and biota methylmercury data, or food web studies coupled with a methylmercury mass balance. Reservoir owners and operators may elect to include it in the reservoir studies for the Statewide Mercury Control Program for Reservoirs. Urban runoff MS4 permittees may elect to coordinate with reservoir owners and operators regarding methylmercury and mercury monitoring in urban runoff discharges (see section 9.5).

Accordingly, the Statewide Mercury Control Program for Reservoirs includes some methylmercury data collection. Methylmercury sources will be considered during program review, particularly to address question 2d, which begins with, "Is it necessary to reduce sources of methylmercury as well as inorganic mercury to attain all TMDL targets applicable to each reservoir?"

Management Question 2b: What is the relative bioavailability of mercury from different sources to reservoirs?

Based on currently available information, we assumed that mercury from all sources to reservoirs is equal in terms of bioavailability. In other words, that the mercury in upland soils and sediments transported via creeks and stormwater is just as bioavailable as mercury recently deposited to the water surface (i.e., mercury from atmospheric deposition). There is emerging evidence that mercury newly-deposited from the atmosphere to the water surface is more bioavailable than other mercury sources, and that watershed mercury sources vary in chemical availability. Factors such as particle size of mercury-containing sediment as well as mineral composition of the sediment may influence biological uptake of mercury. Relative bioavailability has not been taken into account in the current list of proposed implementation actions. This is partly because the amount of mercury from mines overwhelms the amount and bioavailability of mercury from other sources. It is also because very substantial reductions are expected from California and U.S. anthropogenic emissions.

Resolution of this management question is important in that it can help guide efforts to control the most bioavailable sources. If sources differ substantially in bioavailability, then the implementation plan might be able to be revised to address the most bioavailable sources sooner. This question will be addressed through a literature review performed for the planned program review.

Management Question 2c: Are there localized, within-reservoir, methylation or bioaccumulation effects?

Based on currently available information, it has been assumed that mercury, methylating conditions, and bioaccumulation are evenly distributed throughout reservoirs. However, some reservoirs may have more elevated mercury concentrations in one arm compared to the remainder of the reservoir. This is likely to occur in reservoirs filled by several tributaries, only one of which drains mercury mines or gold mines where mercury was used, or where one tributary is dominated by urban runoff. If they exist, these reservoirs may provide a good opportunity to study the benefits of source reduction actions. Answering this question will help to determine whether source reductions are effective in reducing fish methylmercury levels.

This question can be addressed through a program of observation and controlled field experiments. The reservoir owners and operators may elect to include it in the reservoir studies for the Statewide Mercury Control Program for Reservoirs.

If this information is available, staff plans to consider it during program review, particularly to address focusing question 3 stated previously, which begins with, “Is the [uniform] statewide approach effective and appropriate?”

Management Question 3a: Are the TMDL numeric targets appropriately protective of wildlife?

The TMDL numeric targets are based on currently available scientific information, principally methylmercury reference doses and fish consumption rates. Reference doses and adverse effects on wildlife are active research fields. Research currently underway may yield reliable and widely accepted revisions to reference doses within a decade, particularly for wildlife. This question will be addressed through a literature review, to be completed no later than in year 9 of Phase 1, in particular to address focusing question 4 related to modifying targets.

Management Question 3b: Is the sport fish target appropriately protective of human health?

The sport fish target is based on currently available scientific information, principally the USEPA’s methylmercury reference dose and estimated rates of fish consumption across California. The sport fish target applies to the top trophic level. However, in the future more data may become available on human consumption of reservoir fish. If such data were to indicate that people generally consume a “mixed-bag” of reservoir fish (i.e., mix of trophic level 3 and 4 fish), then these data might support development of a site-specific, mixed-bag objective for reservoirs. In which case, an equal site-specific, mixed-bag TMDL numeric target could also be developed.

A consumption survey of anglers at many of the most popular fishing lakes across California might provide adequate data regarding mixed-bag consumption patterns. If a reservoir mixed-bag target were established to protect COMM, and if the sport fish target was modified to not protect COMM, then the applicability of targets to protect WILD and RARE would also need to be evaluated. In other words, the applicability of the prey fish target and CA least tern target would need to be evaluated for protection of wildlife for both WILD and RARE beneficial uses.

In any case, staff plans to re-consider all targets during program review.

Conclusion of adaptive management

The proposed Statewide Mercury Control Program for Reservoirs relies on current mercury science. Mercury science is still advancing rapidly, and it is not yet possible to predict precisely how reservoirs will respond to source reduction, reservoir water chemistry, or fisheries management actions. Much research is underway because this problem of elevated fish methylmercury levels is a worldwide problem, and more research is planned for the future to shed light on the remaining questions. The Water Boards have an obligation to adapt this regulatory program in the future as relevant information becomes available. The Water Boards also have an obligation to protect water quality by taking actions now based on information currently available. This adaptive management plan including its program review at the end of Phase 1 provides the means to fulfill these obligations.

9.13.3 Phase 2 and long-term implementation

Phase 2, i.e., long-term implementation, would not begin until after the State Water Board completes its program review of Phase I and adopts a modification to the Mercury Reservoir Provisions. The State Water Board program review would identify effective and feasible reservoir management actions based on results of the reservoir pilot tests and review of each long-term reservoir management strategy report to determine which, if any, strategies should be implemented during Phase 2 at each impaired reservoir.

Program review would consider other issues (see section 9.13.2, e.g., reservoirs newly determined to be impaired, lower-priority mine sites, etc.) and determine which reservoirs are mercury-impaired and which effective and feasible mercury source control and exposure reduction actions should be required in Phase 2.

Phase 2 would also require monitoring and reporting on mercury control actions. For example, the Water Boards could require that every five years after the effective date of Phase 2, each reservoir owner and operator should submit a progress report to the Water Boards describing (a) progress to date in implementing the long-term reservoir management strategy in each reservoir; (b) results of implementation in reducing fish methylmercury levels; and (c) any recommendations to revise the long-term reservoir management strategy report.

9.14 Protect Additional Reservoirs from Becoming Mercury-Impaired

In closing, this section addresses the third and final main goal of the Statewide Mercury Control Program for Reservoirs (see Chapter 1): to protect additional reservoirs from becoming mercury-impaired. Accomplishing this goal involves maintaining low fish methylmercury levels in non-impaired reservoirs and preventing or reducing mercury problems in non-assessed reservoirs.

Many of the factors related to the mercury problem will be addressed in ways that benefit non-assessed and non-impaired reservoirs as well as impaired reservoirs. In this way, the Statewide Mercury Control Program for Reservoirs and other actions will prevent or reduce mercury problems in reservoirs. The factors include sources (emissions), methylation, and bioaccumulation controls, as described in the following paragraphs.

Mercury source controls are expected to reduce mercury emissions (see Chapter 6 and Appendix H). National and global emission inventories indicate that California anthropogenic emissions have decreased substantially in recent years while emissions in Asia have increased. Global industrial emissions may be the primary anthropogenic source to many mercury-impaired reservoirs on the 2010 303(d) List. Financing and enforcement of international air emissions controls will be needed to make necessary reductions from global sources. The United Nation's Minamata Convention on Mercury is one instrument for reducing mercury emissions from Asia and elsewhere. Once achieved, reductions in atmospheric deposition of mercury from global industrial emissions will be realized across California.

New best management practices for reservoir water chemistry employed to resolve problems other than mercury, but which reduce mercury methylation, may become standard operating practices for reservoirs. For example, global climate change will likely cause other problems. Climate change in California is predicted to increase annual average temperatures, which will cause reservoirs to stratify earlier in the year and turn over later. This means that reservoirs will likely have longer periods of anoxia in the hypolimnion. Warmer water contains less dissolved oxygen than cooler water. In drinking water reservoirs, anoxia causes taste and odor problems from iron and manganese, and can promote phosphorus releases from the sediment that cause eutrophication and more taste and odor problems and fouling in drinking water treatment plants. The frequency of blue-green algae blooms in reservoirs and lakes has already increased, and is expected to continue to increase in response to warming from climate change. Cyanotoxins can be a problem for drinking water and for water contact recreation and wildlife. Climate change is also predicted to increase the frequency of droughts and floods in California, so reservoir water levels are likely to fluctuate even more over several years duration.

In response to climate change, in the future reservoir operators will likely need to nimbly manage water chemistry that could change from year-to-year. Operators will do this to provide drinking water without safety, taste, or odor problems; minimize problems in drinking water treatment facilities; maintain water safe for contact recreation; and to avoid wildlife deaths. Many of the water chemistry practices employed to address these problems will also reduce mercury methylation. In this manner, these practices will spread to reservoirs where fish data have not yet been collected and thereby prevent or reduce mercury problems in reservoirs.

Similarly, it is possible that new best management practices may be developed for reservoir fisheries for reasons other than mercury, but which reduce bioaccumulation, and these may become standard operating practices for reservoir fisheries. More likely is that new fisheries management practices directed at reducing methylmercury levels in sport fish will likely first occur in the reservoirs most popular for fishing for consumption. After operators and sport fishers accept these new practices, it is likely these practices will spread to other reservoirs owned and operated by the same agencies as the most popular fishing sites, and eventually to many other reservoirs. In this manner, these practices will spread to non-assessed reservoirs and thereby prevent or reduce mercury problems in reservoirs.

10 MERCURY AND METHYLMERCURY MONITORING AND PILOT TEST GUIDANCE

Chapter 10 outlines monitoring recommendations, monitoring reports, and methods to achieve the following goals:

1. To ensure effectiveness of inorganic mercury source control actions;
2. To support water chemistry and fisheries management pilot tests; and
3. To achieve long-term attainment of water quality objectives.

Chapter 9 defines the responsible parties and strategies to achieve the goals of the Statewide Mercury Control Program for Reservoirs. Chapter 10 expands on the specific monitoring and reporting required for the various source control actions. Section 10.1 in this chapter presents management questions to assist responsible parties for mine sites, urban runoff, National Pollutant Discharge Elimination System (NPDES) facilities, and dredge and fill activities in the development of sampling and analysis plans for monitoring and then provides guidance to answer those questions. Additional guidance for developing effective water chemistry and fisheries management pilot tests is presented in section 10.2. Recommendations for long-term monitoring of inorganic sources and methylmercury in fish are in section 10.3. Data reporting requirements for all pilot tests and long-term monitoring are in section 10.4.

Appendix J specifies the sampling and analysis procedures and Appendix K assists responsible parties with performing statistical analyses with composite samples. Additionally, Appendix L (Assessment of Compliance with Water Quality Objectives) describes a proposed situation-specific weight of evidence method for assessing compliance with mercury water quality objectives and the numeric targets. The assessment procedures described within Appendix L align with the current water quality assessment procedures for bioaccumulative pollutants. The State Water Board intends to revise the procedure for long-term average water quality objectives for bioaccumulative pollutants in the future. In the meantime, the use of a weight of evidence approach on a case-by-case basis is proposed, such as the weight of evidence procedure provided in Appendix L.

10.1 Monitoring of Mercury Sources

The purpose of this section is to provide guidance to assist responsible parties in developing sampling and analysis plans for mine sites, urban runoff, NPDES facilities, and dredge and fill activities. Water Board staff recommends that sampling and analysis plans be developed for all monitoring conducted for the Statewide Mercury Control Program for Reservoirs. Sampling and analysis plans explain why, when, and who regarding the monitoring effort; what questions the monitoring effort seeks to answer; and field procedures and laboratory analytical methods. Particularly relevant examples of sampling and analysis plans for fish monitoring that may be part of reservoir mercury studies are the plans developed for the Water Boards' Surface Water Ambient Monitoring Program (SWAMP) Bioaccumulation Oversight Group (BOG) lakes studies.

Monitoring and sampling efforts should begin with written plans that provide the questions to be answered and details about how data will be collected and evaluated to answer these questions. The sampling and analysis plans should identify the field procedures and laboratory analytical methods. The quality assurance project plan (QAPP) should explain what quality standards are needed and how they will be achieved. Final reports should describe how quality standards were met and any quality problems observed.

10.1.1 *Mine Sites*

Site Classification Monitoring

For the initial evaluation whether a mine site requires cleanup, five factors will be considered (listed in section 9.2.1 and Table 9.2). If all factors are met, then the mine site will be prioritized for cleanup and classified as a Tier 1 mine site. Cleanup of Tier 1 mine sites should result in quick, measurable reductions in mercury levels in downstream or adjacent reservoirs. This section provides monitoring guidance to classify a mine site as Tier 1.

4. Reservoir sediment total mercury concentrations are elevated compared to modern background levels for the region. Elevated means equal to or greater than 0.6 mg/kg or 0.2 mg/kg in reservoirs located in geologic regions that are naturally enriched in mercury or have trace levels of mercury, respectively. Elevated mercury indicates the potential for substantial mining waste contributions to the reservoir.

The first factor of Tier 1 classification requires sampling of mercury-impaired reservoirs downstream of a mine site. Reservoir sediment should be sampled using USEPA Method 1631 E for total mercury in sediments (see Table 10.1). Reservoir samples should be collected in at least two locations. The first in-reservoir location should be at a depositional area in the downstream reach of each tributary that drains a nearby mine site. The purpose of the second sampling location is to determine if contamination is widespread throughout the reservoir, rather than localized to the inflow.

5. All actively eroding mine sites (either significant active erosion from mass wasting processes; or less significant active erosion from small gullies, rills, and accompanying loss of vegetation) in the reservoir watershed are localized to a relatively small area of the reservoir watershed. In other words, (a) mine sites are present on only one or two tributaries of the reservoir, and (b) all mine sites combined cover no more than 10% of the reservoir watershed area. For assessing localized, the reservoir watershed area does not extend beyond any dam on a reservoir tributary. This characteristic of “localized” means that once the mine site(s) is cleaned up, there should no longer be substantial erosion from the mine site. The remainder of the watershed will be a comparatively larger source of clean sediment to the reservoir, consisting of erosion of native soils with lower mercury concentrations.

Factor 2 requires a geographic analysis of the watershed area by either Geographic Information Systems (GIS) or a desktop map analysis. The USGS’s Mineral Resources Data System (MRDS, USGS 2005) identifies more than 10,000 locations throughout California where productive mercury, gold, and silver mining may have taken place. From this, watershed areas can be estimated to confirm the footprint of a mine site to a downstream impaired reservoir.

6. All actively eroding mine sites in the reservoir watershed are located adjacent to or very close to a reservoir. In other words, mine sites that either discharge directly to the

reservoir or discharge to a tributary to the reservoir less than about 10 km upstream as measured from reservoir high water level. This characteristic of “not far upstream” recognizes that it is particularly difficult to cleanup mining waste in creek channels; without cleanup, creeks will be very long-term sources of mercury to reservoirs.

Similar to Factor 2, this Factor could be evaluated by either GIS or a desktop map analysis. This can be achieved by locating the distance from the perimeter of each mine site to the highest point of the reservoir water level. The high water level of the reservoir can be defined as normal (100%) capacity of reservoir storage. The reservoir spillway height on topographic maps delineates the high water level elevation.

7. There are significant discharges of mercury and/or significant active erosion of mining waste. Significant discharges of mercury means average mercury concentration in discharge of mining wastes is greater than 3 mg/kg from mercury mine sites or 1 mg/kg from non-mercury mine sites (i.e., greater than ten times the allocation for geology surrounding mine sites), or elemental mercury is present and being discharged or is likely to discharge. Significant active erosion means mass wasting processes, such as landslides, slumps, and large gullies.

To determine if significant active erosion is present on a mine site, present-day landscape aerial photography can easily identify scaring from mass wasting. Historic aerial photographs may be useful to compare landscape conditions over time. To determine if significant discharges of mercury are occurring, mining wastes can be sampled directly from stormwater runoff point(s).

8. Other site-specific factors, approved by a Regional Water Board’s Executive Officer, relevant to initiating cleanup and abatement orders within Phase 1.

Factors could include the identification of viable solvent responsible landowners and/or entities that operated the mines and would ultimately be responsible for mine remediation. In many cases, the companies that formerly operated the mines, and even their successor companies, are no longer solvent or existent and this would significantly delay identification of a responsible party with sufficient funds for cleanup.

Post-Cleanup Mine Site Monitoring

Tier 1 mine site responsible parties will be required to develop Mine Site Cleanup Plans and Mine Site Cleanup Reports after the Mine Site Prioritization Plans and Mine Site Prioritization Reports are approved by the Regional Water Board. Both private landowners and federal, state, or local agencies that own or manage mine sites will be issued Cleanup and Abatement Orders by the Regional Water Boards including a time schedule for submission of the cleanup plan and report. The frequency of monitoring will be part of the Mine Site Cleanup Plan subject to approval by the Executive Officer of the applicable Regional Water Board. The purpose of this maintenance and monitoring is to ensure that site remediation actions continue to be effective, and if not, to determine why not, and to fix the problem.

Erosion Control Monitoring for Mine Site Landscapes

Section 9.2.4 and Chapters IV.D.1.c and IV.D.1.d of the Mercury Reservoir Provisions provide minimum requirements of information to include in the cleanup plans and reports. Below are questions to guide the development of effective monitoring actions. Monitoring plans are expected to address the questions presented in this section regarding the effectiveness of erosion control measures to prevent or reduce stormwater discharges of mercury-contaminated mining waste and/or mercury-laden sediment.

Unless specified otherwise in the Mine Site Cleanup Plan, monitoring is expected to consist of (1) visual assessment of the site for evidence of erosion and proper functioning of stormwater controls, and (2) visual assessment or field monitoring of turbidity in stormwater discharge and in upstream and downstream surface waters. Consequently, most reporting can consist of a short narrative and photo documentation. Note that discharges from some mine sites will be subject to NPDES permits. These permits are issued on a site-specific basis for point sources, whereas this section addresses nonpoint sources. Examples of monitoring parameters are mercury, turbidity, suspended sediment, pH, arsenic, cadmium, copper, lead, nickel, and zinc for acid mine drainage and portal discharges. Examples of these monitoring requirements can be found in NPDES permits for gold mines listed in Table 8-2, e.g. Empire Mine (CA0085171) and Washington Mine (CA0085294).

Monitoring should be tailored to the location—landscape or creek. Creeks are common features on mine sites. Mine site areas requiring erosion control may include monitoring both landscape and creek areas, since mining waste was frequently disposed in creeks and adjacent land. Therefore, in remainder of this section, ‘landscape’ refers to the portion of a mine site located outside of a creek and its banks and ‘creeks’ refer to mining waste discharged into a creek or its banks.

Landscape Mining Waste Monitoring Questions

1. **Where will visual inspection of cleanup occur?**

   Erosion control effectiveness monitoring may consist of repeated visual inspections and photographs of the planned cleanup area, adjacent landscapes, and all other locations that have potential soil disturbance. Site maps and as-built plans can be used to document locations of permanent photo-points. Photo-points are required photo documentation sites and established in advanced of the cleanup and should be re-evaluated periodically. The visual inspection should cover the entire site and if an additional location with the potential for significant erosion is observed, it too should be photographed and added as a photo-point. Areas that are lacking vegetation, have evidence of prior erosion, or are composed of a soil type and slope that has a high erodibility factor (k-factor) should be included as photo-points. These visual clues are most obvious late in the dry season when vegetation is dormant. Visual inspection of downstream water clarity is suggested to confirm that the erosion control measures are preventing excessive turbidity.

2. **At what frequency will visual inspections occur?**

   Visual inspections could occur repeatedly before, during and after construction. At least one inspection should occur before construction begins to establish baseline conditions. During construction, erosion control effectiveness should be evaluated at least twice annually: once during a storm event, and again late in the dry season. Subsequent to cleanup, erosion control effectiveness should be evaluated at least once annually late in the dry season.

Storm event monitoring should be timed to occur when the ground is saturated. Storm event monitoring may consist of visual inspection and photo documentation of both the erosion control measures and downstream waters. Visual inspection of the erosion control measures is required to confirm the measures are performing as designed, and are minimizing discharges of mercury mining wastes.

3. How will effectiveness of cleanup efforts be evaluated?

Responsible parties should conduct monitoring to confirm that erosion was minimized by soil stabilization efforts; there was no increase in turbidity from upstream to downstream of the area cleaned up, and there was successful post-cleanup stabilization measures put in place.

In most cases, monitoring mine site cleanups will consist of reviewing the visual inspection findings and evaluating performance of erosion control measures rather than sampling discharges for mercury. Erosion control monitoring is appropriate where cleanup involves earth-moving, slope stabilization, re-vegetation, and storm water run-on and run-off controls. If these erosion control measures perform as designed, then there will be no erosion and, therefore, no discharge of mercury-contaminated mining wastes. Hence, evaluating performance of erosion control measures is appropriate monitoring.

In other cases, monitoring will include sampling discharges for mercury. This is typically the case for waters that are treated prior to discharge, such as acid mine drainage or portal discharges. These treated discharges are point sources subject to NPDES permits. The NPDES permit sampling parameters are determined on a site-specific basis. Examples of monitoring parameters are mercury, turbidity, suspended sediment, pH, arsenic, cadmium, copper, lead, nickel, and zinc. Similar monitoring requirements can be found in NPDES permits for gold mines listed in Table 8-2, e.g. Empire Mine (CA0085171) and Washington Mine (CA0085294).

If post-cleanup stabilization was performed, all plants, including plants used in soil bioengineering systems, that do not survive to thrive within a specified period following planting will be required to be replaced. The performance goal for plants and soil bioengineering systems is eighty-five percent plant survival (percentage as compared to the as-built plans) within five years.

4. What performance criteria for on-site restoration can be used to determine that habitats at impacted sites have recovered to approximate pre-cleanup conditions?

Responsible parties may calculate the percent cover of disturbed surfaces and compare with the percent survival of replanted riparian vegetation to. Site photos documenting the pre-cleanup and post-cleanup conditions may also be used to compare habitat conditions.

5. Has reservoir bottom sediment mercury concentration decreased as a result of remediation of Tier 1 mine sites?

If a mine site is upstream from an impaired reservoir, baseline reservoir sediment mercury concentrations may be sampled and analyzed prior to remediation of Tier 1 mine sites (see Table 7.1). After cleanup is complete, and after several large storm events have delivered fresh sediment to the reservoir, sampling of the reservoir bottom sediment mercury concentrations may be repeated. These data can then be used to evaluate whether mine site remediation has improved reservoir mercury conditions.

Erosion Control Monitoring for Mining Waste in Creeks

In addition to the landscape mining waste monitoring questions, below are questions for mine sites with creeks. As previously stated, a mine site may encompass a creek and, if applicable, monitoring plans can be expanded to address the following questions regarding the effectiveness of restoration to a stable configuration that minimizes excessive erosion or deposition of mercury-contaminated mining waste and/or mercury-laden sediment discharged into creeks:

Creek Mining Waste Questions

1. **What was visually observed in receiving waters before, during, and after storm events?**

Visual assessments are an appropriate means to assess stormwater quality and the effectiveness of management actions to reduce turbidity and prevent discharges of mercury contaminated monitoring waste and/or mercury-laden sediment instead. Turbidity should not increase in the downstream receiving water body as compared to observations upstream and contiguous to cleanup site. Monitoring other water quality constituents should be considered on a site-specific basis (see Landscape Mining Waste Monitoring Question 3).

Responsible parties should conduct monitoring to confirm that erosion was minimized by soil stabilization efforts; there was no increase in turbidity from upstream to downstream of the area cleaned up; and there were successful post-cleanup stabilization measures put in place.

2. **What control measures are necessary to reduce creek incision and promote bank stability and how will effectiveness be measured?**

Some creek erosion control monitoring can be conducted visually, i.e., visual inspections for turbidity. But, streambank stability should also be monitored, which cannot be done by visual means. Instead, it requires monumented cross-sections and profiles of the channel, floodplain, and terraces in all stream reaches that were disturbed.

The purpose of the monumented cross-sections, profiles, and photographs is to track changes in channel plan form, dimensions, and slope; and changes in hillslopes, landscape, and vegetation subsequent to construction of erosion controls. Profiles and cross-sections should be surveyed at photo documentation points located not less than 10 channel widths apart on the stream channel and at time intervals of no less than three years in order to provide a record of changes for ten years after construction.

Re-vegetation and other soil stabilization designs contain construction, operations, and maintenance specifications for geotextile fabrics, soil bioengineering systems, seeding, container plants, plugs, and other re-vegetation and stabilization methods. Responsible parties may routinely check the operations and performance of these systems, if used, to assure their effectiveness.

During construction and five years after completion, erosion control effectiveness should be evaluated at least twice annually. Five years is recommended both to ensure robust and complete revegetation and also to encompass at least one large storm event. If erosion control measures have performed well during years 3 – 5, then frequency can be decreased and erosion control effectiveness should be evaluated at least once annually late in the dry season.

3. **What performance criteria can be used to determine that aquatic habitats will not be altered or have recovered to approximate pre-cleanup conditions?**

On a site-specific basis, it may be appropriate to monitor a creek's aquatic habitat if the cleanup activities are expected to impact the receiving stream.

Monitoring Reports for Landscape and Creek Mine Site Restoration

The purpose of this section is to provide expectations to both the responsible parties and Water Board Staff. The following is intended to support Chapter IV.D.1 of the Mercury Reservoir Provisions.

As previously stated, responsible parties will be required to submit Mine Site Cleanup Reports to the Executive Officer of the applicable Regional Water Board. The reporting frequency will be determined by the Executive Officer of the applicable Regional Water Board. These reports will describe observations related to stormwater and erosion, and any significant changes made within the footprint of mine site remediation and areas both up and down hill influenced by the site. If additional measures are needed or were installed for landscape cleanup to reduce erosion and discharges of mercury, the report will describe the measures implemented. If additional measures are needed for creek cleanups to increase floodplain, creek bank, or creek bed stability or improve vegetation survival, the responsible parties will propose additional measures. Construction of additional measures in floodplain, creek bank, or creek bed is subject to review and written approval of the Executive Officer of the applicable Regional Water Board. Based on the results of the landscape or creek restoration described in the Mine Site Cleanup Report, long-term monitoring and reporting may be required of the responsible party to ensure continued effectiveness. The frequency will be determined by the applicable Regional Water Board.

10.1.2 *Urban Runoff*

The following is intended to support Chapter IV.H of the Mercury Reservoir Provisions. Monitoring of methylmercury in urban runoff (MS4 discharges) is needed to determine whether municipal separate storm sewer systems (MS4s) produce higher concentrations of methylmercury in urban runoff during the dry season compared to the wet season (see Chapters 5 and 6). Dry season runoff tends to contain a larger portion of urban runoff from landscape irrigation and other urban activities compared to natural runoff. There is the potential for dry season MS4 discharges to make comparatively greater contributions to fish methylmercury levels since days are warmer and longer and bioaccumulation periods typically occur during the dry season. As described in Chapter 7, such methylmercury monitoring should be conducted where watersheds of impaired reservoirs are more than 20% developed and there is an MS4 storm drain network that conveys urban runoff directly to the reservoir or to its tributaries. Accordingly, monitoring of methylmercury in urban runoff (MS4 discharges) is needed to answer the following question:

1. **Does urban runoff produce higher concentrations of methylmercury per unit catchment area during wet or dry seasons?**

Monitoring and Reporting Requirements for Urban Runoff

Monitoring of methylmercury in urban runoff is required for MS4s serving a population of 100,000 or more and where more than 20% of a reservoir's watershed is regulated by one or more MS4 NDPES permits and the storm drain conveys urban runoff into the reservoir or its tributaries. The monitoring should identify seasonal trends and relative magnitude (see below) of methylmercury in urban runoff discharges directly to or upstream of a subject reservoir. The monitoring should occur consecutively at least twice during each of one dry season and one wet season. For water samples, total or dissolved methylmercury analysis should be by USEPA Method 1630 modified to achieve a detection limit of 0.009 ng/L or lower and a reporting limit of 0.02 ng/L (see Table 10.1).

The monitoring and reporting results will be evaluated by Water Board staff during the adaptive management review planned at the end of Phase 1 (see section 9.13.2). For this reason, MS4 permittees are urged to coordinate their monitoring efforts with the reservoir coordinated approach (see section 9.8.3) if the reservoir pilot tests are completed in the reservoir downstream from the MS4 and the pilot test includes collecting information about tributary methylmercury and within reservoir methylmercury loading.

Two of the 74 reservoirs on the 2010 303(d)-listed have watersheds that are more than 20% developed and have storm drain networks that convey urban runoff directly to the subject reservoirs or to their tributaries. Puddingstone Reservoir, located between the cities of San Dimas and Pomona in the greater Los Angeles area, and Beach Lake, located in the greater Sacramento region, both have watersheds that are about 30% developed (section 6.5.2). Two MS4 NPDES permits regulate urban runoff in the watersheds of these reservoirs:

- NPDES Permit No. CAS004001 (Order No. R4-2012-0175): Waste discharge requirements for MS4 discharges within the coastal watersheds of Los Angeles County; and
- NPDES Permit No. CAS082597 (Order No. R5-2008-0142): Waste discharge requirements for MS4 discharges from Cities of Citrus Heights, Elk Grove, Folsom, Galt, Rancho Cordova, Sacramento, and County of Sacramento.

For Puddingstone Reservoir, monitoring of total mercury in urban runoff at the point of discharge is already needed to demonstrate compliance with the waste load allocations (WLAs) assigned by the Los Angeles Area Lakes TMDLs and incorporated into the MS4 NPDES permit (Order No. R4-2012-0175; Attachment E, Monitoring and Reporting Program; and Attachment P, San Gabriel River Watershed Management Area). Additionally, monitoring of methylmercury and total mercury in urban runoff is already required twice a year for discharges into Puddingstone Reservoir.

For CAS082597(MS4 service area that includes Beach Lake), monitoring of methylmercury and total mercury in urban runoff is already required for discharges into Lake Natoma and several other water bodies by the Sacramento County MS4 NPDES permit (Order No. R5-2008-0142; Finding No. 93; Monitoring and Reporting Program Requirements; and Table B). This MS4 NPDES permit also requires evaluation of total mercury and methylmercury data collected during the previous permit cycle to determine average annual methylmercury and total mercury concentrations and loads discharged over a range of wet and dry years. However this permit monitoring is not required at Beach Lake.

10.1.3 *NPDES Facilities*

The following is intended to support Chapter IV.G of the Mercury Reservoir Provisions. During Phase 1 of implementation, the State and Regional Water Boards will revise individual NPDES facility permits for large and small dischargers to include monitoring requirements to answer the following questions:

1. **What is the concentration of total mercury in effluent, and how does it compare to waste load allocations (WLAs) and numeric effluent limitations (NELs)?**
2. **What is the concentration of methylmercury in effluent from pond treatment systems, and how does it vary seasonally?**

NPDES permit programs already provide for extensive tracking and reporting procedures by dischargers and Water Boards (see section 9.7.5). Monitoring of total mercury in effluent from large and small dischargers is needed to assess compliance with NELs and hence compliance with WLAs. The monitoring locations for NELs should be the effluent monitoring points described in individual NPDES permits. The frequency of effluent total mercury monitoring to evaluate compliance with the NELs and reporting requirements will be determined by the applicable Regional Water Board. More frequent monitoring provides early warning of potential to exceed an NEL. In this manner, more frequent monitoring provides valuable information and time for dischargers to take corrective actions before the end of the annual averaging period. The preferable analytical method to monitor mercury from NPDES discharges is USEPA Method 245.7 with a reporting limit of 5.0 ng/L (see Table 10.1).

In addition, monitoring of methylmercury in effluent is proposed for facilities that meet the following criteria:

- Facility discharge is regulated by an individual NPDES permit;
- Facility discharge is directly to or upstream of a subject reservoir;
- Facility design flow is greater than 0.2 MGD; and
- Facility uses one or more treatment pond systems (e.g., oxidation, facilitative, settling, or stabilization ponds) or facility is a municipal wastewater treatment plant that uses secondary treatment processes without nitrification/denitrification and filtration.

Facilities that meet these criteria as of May 2015 are identified on Table 8.2. The number of facilities that may be required to monitor effluent methylmercury may decrease as facilities complete treatment upgrades to include nitrification/denitrification and filtration.

Effluent methylmercury monitoring is proposed on a quarterly basis for at two years beginning in January of year 1 of Phase 1 for facilities listed in Table 8.1. The monitoring results may be submitted in an annual report. If all methylmercury sample results in the first calendar year are below the detection limit of 0.02 ng/L, then the permittee may discontinue the monitoring. The preferable analytical method to monitor mercury from NPDES discharges is USEPA Method 1630 with a detection limit of $\leq$ 0.02 ng/L (see Table 10.1).The methylmercury monitoring locations should be the same as for total mercury, which are the effluent monitoring points described in individual NPDES permits. Quarterly monitoring is needed to have adequate data to assess seasonal and inter-annual variability.

Methylmercury monitoring in addition to total mercury monitoring is needed for the adaptive management review at the end of Phase 1. At that time, it will be determined whether applicable NPDES-permitted facilities need to perform other methylmercury monitoring or control actions for either or both total mercury and methylmercury during Phase 2 to achieve the fish methylmercury objectives (see Chapter 8 for more discussion).

10.1.4 ***Dredge and Fill Activities***

Dredging and earth-moving activities undertaken for purposes other than mercury remediation (cleanup) that may discharge or disturb mercury that may have originated from historical mines to any impaired, non-impaired, or non-assessed reservoir will need to minimize discharges of mercury to reservoirs by reasonable and feasible means. Section 9.10 states the responsible parties and generally describes the implementation plan for dredging and earth-moving activities. The Mercury Reservoir Provisions Chapters III.A and IV.E of the Mercury Reservoir Provisions require the development of a Site Characterization Plan, Dredging Work Plan, Maintenance and Monitoring Plan, and annual reports. Additional reporting to document actions taken to minimize the discharge of mercury into surface waters may be required by the Water Boards. This section will guide responsible parties to develop effective Dredging Work Plans and Maintenance and Monitoring Plans.

Prior to commencing activities, the Mercury Reservoir Provisions Chapter III.A.3.c require project applicants to submit a Dredging Work Plan describing measures they will take to minimize discharge of mercury during and after undertaking activities that disturb mercury-contaminated sediments. Project applicants should not commence activities before they receive written approval from the Water Board Executive Officer of the maintenance and monitoring plan. A Maintenance and Monitoring Plan should also submit a dredging work plan to the Water Board describing the actions the discharger will take to ensure that the mercury and erosion control measures remain effective from the commencement of an activity through no less than two years after the activity is completed.

During-activity and post-activity maintenance, monitoring, and reporting for dredging (including on-site disposal) are needed to ensure that the measures minimize scour and erosion and discharge controls continue to be effective. After completion of the activities, project applicants should submit annual reports for no less than two years to document compliance with the approved maintenance and monitoring plan (see section 9.2.4 for additional details on maintenance, monitoring, and reporting).

Prior to disposing of dredged sediments, the Mercury Reservoir Provisions require project applicants to submit designs and plans for on-site and off-site disposal of dredged sediments to the applicable Regional Water Board. Designs are not required for disposal at a permitted municipal or hazardous waste landfill. On-site or nearby off-site disposal of mercury-contaminated sediments may be appropriate for most activities. Off-site disposal at solid or hazardous waste landfills is unlikely to be reasonable or feasible for most activities due to monetary and environmental costs from long haul distances.

Implementation actions for on-site or nearby off-site disposal vary from simpler erosion control actions to complex landfill construction depending on site-specific conditions, and are the same as provided for mine sites (section 9.2.4). Project applicants should not commence activities before they receive written approval from the Water Board Executive Officer of the on-site or nearby off-site disposal plan.

10.2 Water Chemistry and Fisheries Pilot Tests and Associated Studies

This section provides questions to address water chemistry or fisheries management pilot studies mercury-impaired reservoirs (see Table S.1). The Mercury Reservoir Provisions Chapter IV.F.1 directs the development of Pilot Test Work Plans which must be submitted to the Water Board. Reservoirs that are part of hydropower projects licensed by the Federal Energy Regulatory Commission ("FERC-licensed") would be excluded from mercury pilot test requirements in Phase 1.

The Mercury Reservoir Provisions allow reservoir owners or operators the option of conducting coordinated pilot tests and associated studies rather than conducting them individually and independently. Key features of coordinated programs are provided in sections 9.8.1 and 9.8.3, as are the scope of actions to be evaluated in pilot tests. Parties who choose to coordinate their studies may conduct pilot tests and associated studies in a few, targeted reservoirs. Parties who choose to work independently will be required to conduct these pilot tests and associated studies in each of their reservoirs included in this Statewide Mercury Control Program for Reservoirs.

Phase 1 of implementation includes pilot tests (i.e., field trials) and associated studies of reservoir (a) water chemistry controls to reduce in-reservoir methylmercury production and possibly increase demethylation, and (b) fisheries management practices to reduce fish methylmercury levels. The information generated from these pilot tests and associated studies will be evaluated by the State Water Board when it reviews the Mercury Reservoir Provisions at the end of Phase 1 and considers potential Phase 2 reservoir management options.

The Mercury Reservoir Provisions direct that the actions in Phase 1 are to complete pilot tests of water chemistry and fisheries management practices to reduce fish mercury concentrations. Although not compelled by the Mercury Reservoir Provisions, pilot tests should be supported by associated studies and control (i.e., "reference") reservoirs. Associated studies are ideas that may improve technical validity or efficiency that should be vetted with the Technical Review

Committee. As such, monitoring of statewide trends is needed to avoid reaching false conclusions about pilot studies. The SWAMP BOG lakes studies[1] monitoring plan urges statewide and regional trend data to be gathered to determine if a statewide increasing trend is obscuring the beneficial effects of management actions. In the absence of awareness of such a trend, false conclusions could be drawn that actions are not having the desired effect.

The reservoir management questions presented below are intended to focus the development and execution of pilot tests.

Pilot Test Selection Questions

The questions in this section should be considered during meetings with the Technical Review Committee.

1. How does reservoirs water chemistry differ among reservoirs?

Answering question 1 will inform whether reservoir water chemistry management practices could be uniform or need to vary based on reservoir type, setting, and location. Considerations for mercury methylation include duration and degrees of thermal stratification (see discussion in section 9.13.2 regarding management question 1c).

2. How do reservoir fisheries differ among reservoirs?

Answering question 2 will inform how fisheries management practices will need to vary across California. Currently, some considerations for variations in fisheries management include (a) trophy black bass designation, (b) importance of sport fishing to the local economy, (c) self-sustaining fisheries, and (d) fish stocking practices. Fish are stocked for many reasons, e.g. to provide recreational opportunities for California’s anglers where fish populations are not self-sustaining, and for conservation and restoration of native fish species.

3. What pilot tests and associated studies should be conducted and where?

Question 3 should be considered together with other water and fisheries chemistry questions, as well as accounting for practical and funding constraints. Development of criteria and a process to select reservoirs for coordinated studies and pilot tests should be coordinated with Water Board staff and the Technical Review Committee. A preliminary list of study, pilot test, and control (or reference) sites is provided in section 9.8.3.

Water Chemistry Pilot Tests Management Questions

Reservoir water chemistry pilot tests should be designed to answer methylmercury management questions. The management questions below provide a starting point for pilot tests and associated studies of water chemistry controls to reduce in-reservoir methylmercury production and possibly increase demethylation. These may be refined based on input from responsible parties and other interested parties, and the Technical Review Committee.

[1] SWAMP BOG 2014 (low concentrations of contaminants study) and 2007 (two-year screening study) sampling and analysis plans are available at: www.waterboards.ca.gov/water_issues/programs/swamp/lakes_study.shtml

These management questions or refinements should be included in the sampling and analysis plan submitted to the Technical Review Committee (see Chapter 9) for review and subsequent submittal to the Water Board(s) for approval. Additional sampling and analysis plan guidance is provided in Appendix J: Sampling and Analysis Procedures.

Water Chemistry Management Questions

1a: What are the baseline conditions relative to mercury inputs, mercury cycling, and methylmercury production in the reservoirs?

1b: What are the baseline conditions in biosentinel fish?

1c: Is inter-annual variation high enough to potentially confound interpretation of pilot test results?

Questions 1a – 1c address formation of a baseline data set to use in future comparisons. An important baseline condition is fish methylmercury levels, particularly a statistically robust data set against which statistically significant comparisons may be made. Sport fish may be used to establish this baseline, but sport fish are several years old. Since sport fish have accumulated methylmercury over several years, and since reservoir conditions and mercury cycling may have changed over these years, sport fish are not a precise indicator of specific reservoir conditions. In contrast, young fish that have accumulated their mercury over a year or less are more precise indicators of specific reservoir conditions. Biota that are precise indicators are commonly called "biosentinels." While sport fish have been monitored in all the reservoirs included in this program, biosentinel fish have not. The 2014 SWAMP BOG clean lakes study collected prey fish of 25 – 100 mm length from several species at several reservoirs throughout California. This effort will provide information helpful to selecting biosentinel fish (i.e., selecting size and species) to monitor in reservoirs included in this program.

Reservoir baseline conditions include many other factors such as the following:

(a) Water inputs, i.e., total mercury and methylmercury concentrations in water from tributaries, canals, and overland flow, and whether they change seasonally or during storm (or other) events, and total mercury in precipitation;

(b) Circulation patterns, i.e., whether water inputs mix in the reservoir or have a short-circuit flow path through it, and whether the reservoir is well-mixed throughout the year or stratified in some seasons;

(c) Reservoir water chemistry and in-reservoir methylmercury production, i.e., aqueous total mercury, suspended particulate total mercury, and aqueous methylmercury in the epilimnion, metalimnion, and hypolimnion; and depth profiles of chlorophyll-*a*, dissolved oxygen, and temperature; and seasonal changes in these factors;

(d) Reservoir bottom sediment chemistry, i.e., total mercury, methylmercury, and organic carbon concentration in bottom sediment, and whether sediments are fine-grained or coarse materials; and

(e) Many other factors, including reservoir and fisheries operations, food web and fish assemblage.

Inter-annual variations can occur for natural reasons, such as high precipitation one year and drought the next, or they can occur due to reservoir operations, such as drawdown to accommodate maintenance and construction projects. In particular, re-fill after extreme drawdown is likely to cause an increase in methylmercury production, which could confound interpretation of results. The studies should be designed to account for or to measure inter-annual variation.

2a. Where and when is methylation occurring in reservoirs and what are the controlling factors?

2b. Are there localized, within-reservoir, methylation effects?

Answers to questions 2a and 2b will inform development and evaluation of reservoir water chemistry management practices to suppress methylation and promote demethylation (see discussion in section 9.13.2 regarding management questions 1a and 2c). Currently available information indicates methylation is mostly occurring during seasonal stratification in reservoir bottom sediments, from which it diffuses into the water column, and that the absence of oxygen and nitrate are important controlling factors. However, reservoirs also produce some methylmercury in the metalimnion and epilimnion, and in contiguous wetlands and marshes, and photodemethylation occurs down to the photic depth. Less information is available about these processes partly because they are believed to produce less methylmercury than is produced at the sediment-water interface.

Furthermore, these questions must be addressed to determine whether mercury and methylating conditions are evenly distributed throughout reservoirs. Some reservoirs may have somewhat elevated sediment mercury concentrations in one arm compared to the remainder of the reservoir. This is likely to occur in reservoirs filled by several tributaries, only one of which drains mercury mines or gold mines where mercury was used. If conditions for methylation are evenly distributed throughout the reservoir, then the arm that drains the mines should have sediment and biosentinel fish with elevated methylmercury levels.

In addition, some reservoirs may have areas that have lower dissolved oxygen compared to the remainder of the reservoir. Consequently, such areas could have increased sediment methylmercury concentrations in spite of having similar sediment total mercury concentrations compared to the remainder of the reservoir.

In the same way, some reservoirs may have somewhat elevated chlorophyll-*a* concentrations in one arm compared to the remainder of the reservoir. This is likely to occur in reservoir filled by several tributaries, only one of which drains agricultural, dairy, ranching, or other land uses that often contribute much higher levels of nutrients. If methylating conditions are evenly distributed throughout the reservoir, then the arm that drains the areas of higher nutrients may have biosentinel fish with lower methylmercury levels due to biodilution.

3. How will effectiveness of water chemistry pilot tests be evaluated?

In order to answer Question 3, a quality assurance project plan (QAPP) (see Appendix J.3) should include methods to determine pilot test efficacy, the statistical analyses needed to perform these evaluations, including the required sample size and statistical power to perform the analysis.

Pilot test work plans should consider use of biosentinel fish rather than sport fish to determine whether pilot tests statistically significantly reduce fish methylmercury levels. Chapter 9 provides greater detail on the use of biosentinels. Appendix J: Sampling and Analysis Procedures expands on the sampling and analysis procedures for pilot tests and associated studies, and Appendix K: Statistical Analyses with Composite Samples provides directions for performing statistical analyses with composite samples.

Fisheries Management Pilot Tests Management Questions

Reservoir fisheries pilot tests should be designed to answer methylmercury management questions. The management questions below provide a starting point for pilot tests that involve fisheries management practices to reduce bioaccumulation and fish methylmercury levels. These may be refined based on input from responsible parties and other interested parties, and the Technical Review Committee.

These management questions or refinements should be included in the sampling and analysis plans submitted for review by the Technical Review Committee (see Chapter 9) and subsequent submittal to the water Board(s) for written approval.

Fisheries Management Questions

1a: What are the baseline conditions relative to methylmercury bioaccumulation in the reservoirs?

1b: What are baseline conditions in biosentinel fish?

1c: Is inter-annual variation high enough to confound interpretation of results?

Questions 1a – 1c address formation of baseline conditions to use in future comparisons. An important baseline condition is fish methylmercury levels, particularly a statistically robust data set against which statistically significant comparisons may be made. Sport fish may be used to establish this baseline, but sport fish are several years old. Since sport fish have accumulated methylmercury over several years, and since reservoir conditions and mercury cycling may have changed over these years, sport fish are not a precise indicator of specific reservoir conditions. In contrast, young fish that have accumulated their mercury over a year or less are more precise indicators of specific reservoir conditions. Biota that are precise indicators are commonly called “biosentinels.” While sport fish have been monitored in all the reservoirs included in this program, biosentinel fish have not. The 2014 SWAMP BOG clean lakes study collected prey fish of 25 – 100 mm length from several species. This effort provided information helpful to selecting biosentinel fish (i.e., selecting size and species) to monitor in reservoirs included in this program.

Reservoir bioaccumulation baseline conditions include several factors such as food web and fish assemblage, and productivity status (oligotrophic, mesotrophic, or eutrophic; and corresponding levels of chlorophyll-*a*). Inter-annual variations in these factors can occur for natural and management reasons, such as natural variations in prey species and stocking of sport fish. The studies should be designed to account for or to measure inter-annual variation.

2a. Where and when is bioaccumulation occurring in the reservoirs and what are the controlling factors?

2b. Are there localized, within-reservoir bioaccumulation effects?

Answers to questions 4a and 4b will inform development and evaluation of fisheries management practices to reduce fish methylmercury levels (see discussion in section 9.13.2 regarding management question 1b). Currently available information suggests the largest amount of bioaccumulation occurs after fall over turn in reservoirs in the Coast Ranges. Additional bioaccumulation occurs in the growing season in the epilimnion and metalimnion.

Furthermore, these questions can be addressed to determine whether bioaccumulation is evenly distributed throughout reservoirs. Some reservoirs may have somewhat elevated sediment mercury concentrations in one arm compared to the remainder of the reservoir. This is likely to occur in reservoirs filled by several tributaries, only one of which drains mercury mines or gold mines where mercury was used. If all other conditions are the same, then the arm that drains the mines should have biosentinel fish with elevated methylmercury levels.

In the same way, some reservoirs may have somewhat elevated chlorophyll-*a* concentrations in one arm compared to the remainder of the reservoir. This is likely to occur in reservoir filled by several tributaries, only one of which drains agricultural, dairy, ranching, or other land uses that often contribute much higher levels of nutrients. Again, if all other conditions are the same, then the arm that drains the areas of higher nutrients may have fish with lower methylmercury levels.

Note that question 2 and this discussion have some overlap between water chemistry and fisheries management.

3. How will effectiveness of fisheries management pilot tests be evaluated?

In order to answer Question 3, a QAPP (see Appendix J.3) should include the statistical analyses needed to perform these evaluations, including the required sample size and statistical power to perform the analysis. Appendix J: Sampling and Analysis Procedures expands on the sampling and analysis procedures for pilot tests and associated studies, and Appendix K: Statistical Analyses with Composite Samples provides directions for performing statistical analyses with composite samples.

10.3 Long-Term Monitoring

The purpose of long-term monitoring is to provide confirmation that the program goals are achieved and maintained. A comprehensive progress review will be conducted at the end of the first phase of implementation, and this review may result in modifications to this long-term monitoring plan. This section is a recommendation to responsible parties and is not required by the Mercury Reservoir Provisions.

10.3.1 *Long-Term Inorganic Mercury Source Monitoring*

Monitoring is needed to ensure ongoing, continued effectiveness of mercury source control actions. Such monitoring varies by source category.

Monitoring requirements for mine sites and downstream from mine sites will be developed on a site-specific basis (described previously in section 10.1.1). The purpose of this monitoring is to ensure that site remediation actions continue to be effective, and if not, to determine why not, and to fix the problem.

The State or Regional Water Boards will determine the need for and scope of monitoring requirements for urban runoff (MS4 discharges) for Phase 2 of implementation during program review at the end of Phase 1 of implementation.

Monitoring of total mercury in effluent from large and small NPDES-permitted facilities will continue to be required in the NPDES permits to assess compliance with WLAs and NELs. The State or Regional Water Boards will determine future needs for effluent methylmercury monitoring during program review at the end of Phase 1 of implementation.

10.3.2 *Long-Term Fish Monitoring in Impaired Reservoirs*

The purpose of fish monitoring is to provide confirmation that the fish methylmercury targets and objectives are achieved and maintained after reservoir management practices are implemented in Phase 2. Reservoir owners and operators are required to develop a long-term reservoir management strategy and subsequent report for each mercury-impaired reservoir. The long-term reservoir management strategy report shall identify feasible actions and a time schedule that will be taken to achieve the mercury water quality objectives. The management strategy shall include an assessment schedule that includes periodic monitoring to ensure the management strategy is effective at maintaining the mercury water quality objectives. Responsible parties will need to conduct fish monitoring in each of their reservoirs included in this program to demonstrate compliance with the objectives.

Reservoir owners and operators of each impaired reservoir will submit a Long-term Reservoir Management Strategy Report (see Chapter IV.F.1 of the Mercury Reservoir Provisions) to the Water Boards within 10 years of the Effective Date of the Mercury Reservoir Provisions. Subsequently, on-going monitoring is needed to demonstrate that compliance with fish tissue objectives is maintained. It is anticipated this monitoring would occur once each decade. Compliance with the fish water quality objectives will need to conform to the most recent procedures specified by the objectives (see Chapter 1).

10.3.3 *Evaluating Statewide Long-Term Mercury Trends in Fish*

The SWAMP BOG's Sampling and Analysis Plan for Long-Term Monitoring of Bass Lakes and Reservoirs in California (SWAMP 2015a) offers guidance for analyzing trends in long-term fish tissue sampling. The questions below are drawn from SWAMP BOG's management questions for reservoir owners and operators to consider while evaluating trend data.

1) What is the trend in statewide average bass mercury concentrations in fish in reservoirs?

Mercury TMDLs also have been developed for other water bodies, including the Delta, San Francisco Bay, and some lakes and reservoirs. For all of the mercury control plans in the state, it is critically important to know whether food web mercury concentrations are trending up or down on a regional or statewide scale. A statewide increasing trend could obscure the beneficial effects of management actions to reduce mercury bioaccumulation. In the absence of awareness of such a trend, false conclusions could be drawn that actions are not having the desired effect. On the other hand, the existence of a general declining trend could give the impression that actions are more effective than they actually are.

It is plausible to hypothesize that food web mercury could be increasing across the state, either due to increasing atmospheric mercury emissions in Asia (Chen et al. 2012, Drevnick et al. 2015) or due to global warming (Schneider et al. 2009). Several recent studies have reported evidence of regional increases in food web mercury in northcentral North America (e.g., Monson 2009, Monson et al. 2011, Gandhi et al. 2014), although the most recent data from Minnesota suggest a return to a long-term pattern of decline (Bruce Monson, personal communication). Hypothesized causes of these regional trends include global atmospheric emissions, climate change, invasive species, and changes in food web structure.

The data needed to answer this management question are measurements of statewide average concentrations that are repeated over time. The large number and wide distribution of bass lakes that have been identified as priorities for sampling provide a population of water bodies that can be sampled to assess statewide and regional trends in food web mercury over time. Repeated rounds of sampling of randomly selected subsets of these lakes would yield a time series of representative, average statewide concentrations. These statewide averages would be based on concentrations in black bass, which have been demonstrated to be indicator species that are representative of conditions in the water body where they are collected and that yield data that are comparable across water bodies and over time.

2) Secondary Management Questions to Guide Data Interpretation

a. What fractions of the lakes show decreases, increases, or no change in mercury concentration in fish?

Monitoring of mercury in clusters of lakes in other regions of North America have shown that temporal trends in fish mercury levels commonly vary among lakes, with some lakes showing decreases, some showing increases, and some showing no change. Examination of fish mercury levels from the small number of California lakes that have been sampled twice (first in 2007 – 2008 and again in 2012 or 2013) suggest that this outcome can be expected in California as well.

b. What factors appear to be driving changes in mercury concentrations in fish?

Environmental managers will want to know what causal factors of processes are contributing to such variability in temporal trends among lakes. The data obtained from pilot tests and associated studies will be used to develop hypotheses regarding factors and processes causing observed trends. The development of hypotheses may stimulate focused investigations by scientists in academic, state, and federal sectors.

10.4 Data Reporting Requirements

California Environmental Data Exchange Network (CEDEN) consolidates California's data in a central location, where it can be easily accessed and used for statewide management efforts. Data collected during the pilot tests and associated studies and any ongoing water, sediment, and fish monitoring, should be entered into CEDEN and comply with the State Water Boards' Quality Assurance Project Plan standards (see Appendix J.3). Types of data that can be accepted by CEDEN are water chemistry, sediment chemistry, toxicity, tissue, and bioassessment data.

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