



**Statewide Total Maximum Daily Load for:
Mercury and Methylmercury for 31 Impaired
Segments in Arizona Waterbodies**

Table of Contents

Table of Contents.....	ii
List of Tables.....	iv
List of Figures.....	v
Abbreviated Terms.....	vi
Section 1 Introduction.....	1
Section 2 Problem Statement.....	2
Section 3 Setting.....	6
3.1 Geology and Topography.....	9
3.2 Climate.....	9
3.3 Land Cover.....	9
Section 4 Water Quality Standards and Numeric Endpoint Targets.....	13
4.1 Water Quality Standards.....	13
4.1.1 Designated Uses.....	13
4.1.2 Water Quality Criteria.....	17
4.3.1 Antidegradation Policy.....	18
4.2 TMDL Numeric Endpoint Targets.....	18
4.3 Supplemental Criteria and Screening Values.....	18
Section 5 Data Evaluation.....	21
5.1 Water Quality Data – Streams and Lakes.....	22
5.2 Water Quality Data – Wells and Groundwater.....	25
5.3 Sediment Data.....	25
5.4 Fish Tissue Data.....	26
5.5 Summary of Findings.....	27
Section 6 Source Assessment.....	28
6.1 Pollutant Transport Mechanisms.....	30
6.2 Point Sources.....	30
6.3 Nonpoint Sources.....	34
6.3.1 Atmospheric Deposition.....	34
6.3.2 Geological Background Erosion.....	34
6.3.3 Stream Sediment and Floodplain Sources (including Mining Sources).....	34
6.4 Estimated Existing Delivered Pollutant Loads.....	35
Section 7 Technical Approach.....	40
7.1 Technical Approaches Considered.....	40
7.2 Selected Approach.....	41
Section 8 Linkage Analysis.....	42

8.1	Spatial Patterns.....	42
8.2	Seasonal Patterns.....	43
8.3	Calibration to Observed Data.....	43
Section 9 TMDL Development		44
9.1	Loading Capacity and Allocations.....	44
9.1.1	Wasteload Allocations	49
9.1.2	Load Allocations	55
9.2	Seasonality and Critical Conditions	58
9.3	Margin of Safety.....	58
Section 10 Implementation Planning		59
10.1	Point Sources	59
10.2	Nonpoint Sources	61
10.2.1	Historical Considerations and Completed Actions	61
10.2.2	Ongoing Actions.....	62
10.2.3	Future Actions and Monitoring	63
10.3	Stakeholder Collaboration.....	67
10.4	5-Year Assessment and Monitoring.....	68
Section 11 Public Participation		68
Section 12 Administrative Transparency and Generative AI Disclosure.....		70
Section 13 References.....		70

List of Tables

Table 1. Impaired Waterbody, Pollutant, Uses, and Causes of Impairment.	4
Table 2. Areal Extent of Land Use Categories in Arizona based on NLCD 2021.	11
Table 3. Designated Uses for Waterbodies in Arizona.	13
Table 4. Designated Uses of the Hg-Impaired Waterbodies in Arizona.	14
Table 5. Applicable Water Quality Criteria for Hg.	17
Table 6. TMDL Numeric Targets for Hg in Water.	18
Table 7. Hg BAF Estimates.	21
Table 8. TMDL Supplemental Criteria for Total Recoverable Hg to Address Fish Consumption Impairments.	21
Table 9. Summary Statistics for Available Surface Water Hg Data.	22
Table 10. Summary Statistics for Available Sediment Hg Data.	25
Table 11. Sample and Exceedance Counts by Species of Interest, Based on the Fish Tissue MeHg Criterion of 0.3 mg/kg.	26
Table 12. Point and Nonpoint Sources of Hg Load.	28
Table 13. Point Sources with NPDES Permits.	31
Table 14. Average Annual Total Hg Loads Delivered to Each Impaired WBID ^a	35
Table 15. Percentage Contribution of Total Hg Sources Delivered to Each Impaired WBID ^a	38
Table 16. Total Recoverable Hg Loading Capacities for Impaired Waterbodies.	45
Table 17. Needed Percent Reductions in Total Hg Loads to Achieve TMDL Targets.	47
Table 18. Wasteload Allocations for Permitted Point Sources.	50
Table 19. WLA Matrix Summary by NPDES Permit Number.	52
Table 20. Load Allocations for Hg Impaired Segments.	56
Table 21. AZPDES Permittees and Permit Renewal Cycles.	60
Table 22. Point Source Monitoring Plan.	60
Table 23. Completed Hg Mitigation and Management Activities.	62
Table 24. Ongoing Activities.	63
Table 25. Phase I Activities.	65
Table 26. Phase II Activities.	66
Table 27. Phase III Activities.	67

List of Figures

Figure 1. Schematic of mercury cycling in aquatic environment.....	3
Figure 2. Map of Mercury-Impaired Waters Included in the Statewide TMDL Analysis.....	8
Figure 3. Arizona Land Use/Cover from NLCD 2021.....	10
Figure 4. Arizona Land Cover Change from NLCD 2001-2021	12
Figure 5. Hg in Arizona Fish Species.....	20
Figure 6. Boxplots of Water Column THg Concentrations by Waterbody Type.....	23
Figure 7. Boxplots of Water Column MeHg Concentrations by Waterbody Type.	24
Figure 8. Boxplots of Fish Tissue MeHg Concentrations by Species.	27
Figure 9. Locations of NPDES Permitted Point Sources.	33
Figure 10. Phased Restoration Framework - Work Flow Funnel.	64

Abbreviated Terms

§	Section (usually a section of federal or state rules or statutes)
§ 303(d)	Refers to section 303 subsection (d) of the Clean Water Act (Water Quality Impairment), or a list of impaired waterbodies required by this section
§ 305(b)	Refers to section 305 subsection (b) of the Clean Water Act (Water Quality Assessment)
μ	Micro, one-one thousandth
μg/L	Micrograms per Liter
A&Wc	Aquatic and Wildlife, Cold Water Designated Use
A&Ww	Aquatic and Wildlife, Warm Water Designated Use
A.A.C.	Arizona Administrative Code
ADEQ	Arizona Department of Environmental Quality
AgI	Agriculture Irrigation Designated Use
AgL	Agriculture Livestock Designated Use
AI	Artificial Intelligence
A.R.S.	Arizona Revised Statutes
AZPDES	Arizona Pollutant Discharge Elimination System
BAF	Biological Accumulation Factor
CCF	Channel Catfish
C.F.R.	Code of Federal Regulations (refers to citations in the federal administrative rules)
cfs	Cubic Feet per Second
CMAQ	Community Multiscale Air Quality
CVAA	Cold Vapor Atomic Absorption
CWA	Clean Water Act
DL	Detection Limit
DMR	Discharge Monitoring Report
DOI	United States Department of the Interior
EPA	United States Environmental Protection Agency
FBC	Full Body Contact Designated Use
FC	Fish Consumption Designated Use

FHC	Flathead Catfish
GWLF	Generalized Watershed Loading Function
Hg	Mercury
HUC	Hydrologic Unit Code
km	Kilometer
LMB	Largemouth Bass
LA	Load Allocation
lb	Pound
LC	Loading Capacity
MAD	Median Absolute Difference
MATS	Mercury and Air Toxics Standards
m	Meter
MeHg	Methylmercury
mi	Mile
MI	Mining Index (count of Au, Ag, and Hg mines per square kilometer area)
MGD	Million Gallons per Day
mg/kg	Milligrams per Kilogram
mg/L	Milligrams per Liter
mL	Milliliter
mm	Millimeter
MOS	Margin of Safety
MS4	Municipal Separate Storm Sewer System
NA	Not Applicable
NB	Natural Background
NADP-MDN	National Atmospheric Deposition Program Mercury Deposition Network
ng/g	Nanograms per Gram
ng/L	Nanograms per Liter
NHD	National Hydrography Dataset
NHDPlusV2	National Hydrography Dataset Plus version 2
NLCD	National Land Cover Database

NOAA	National Oceanic and Atmospheric Administration
Non-POTW	Non-Publicly Owned Treatment Works
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint Source
PBC	Partial Body Contact Designated Use
POTW	Publicly Owned Treatment Works
ppm	Parts per Million
RL	Reporting Limit
SPARROW	Spatially Referenced Regression on Watershed Attributes
SUN	Sunfish Species
SSIU	Sampling and Source Identification Unite
TMDL	Total Maximum Daily Load
THg	Total Mercury
TSS	Total Suspended Solids
USGS	United States Geological Survey
WASP	Water Quality Analysis Simulation Program
WBID	Waterbody Identifier
WBM	Water-Balance Model
WIU	Watershed Improvement Unit
WLA	Wasteload Allocation
WNAM	Western North American Mercury
WQP	Water Quality Portal
WQS	Water Quality Standards
WWTP	Wastewater Treatment Plant

Section 1 Introduction

Every two years, the Clean Water Act (CWA) § 305(b) and § 303(d) requires the Arizona Department of Environmental Quality (ADEQ) to assess the health of Arizona surface waters against established water quality standards (WQS). Following United States Environmental Protection Agency (EPA) guidance, ADEQ combines these requirements into an Integrated Report. The CWA also requires states to establish a priority ranking for impaired waters and to develop and implement a Total Maximum Daily Load (TMDL) for each §303(d)-listed impairment. Regulations at 40 C.F.R. § 130.7(c)(1) further require that “[e]ach State shall establish TMDLs for the water quality limited segments identified” in its Integrated Report. This report summarizes the TMDL development process for Arizona waters listed as impaired due to mercury (Hg) and/or methylmercury (MeHg).

A TMDL is the maximum amount of a pollutant that a waterbody can receive and still meet WQS. It is defined as the sum of the individual wasteload allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources (NPSs), plus natural background (NB) levels (40 CFR §130.2). The purpose of a TMDL is to identify the pollutant load reductions needed to return a waterbody to attainment with WQS, thereby supporting the designated uses of the waterbody. Practically speaking, a TMDL typically consists of identifying the pollutant of concern, estimating the waterbody’s assimilative capacity, estimating the existing pollutant loads from sources in the watershed, determining the allowable loading from the sources and the reductions needed to meet WQS, and allocating the pollutant load among the sources. TMDLs must be established for impaired waters within 15 years of their initial identification on the § 303(d) list per regulations in the Arizona Revised Statutes (A.R.S.) §49-233. It is important to remember that a TMDL is a planning tool, and while it outlines the necessary load reductions and provides a potential path towards improvements, it does not guarantee that those actions will be implemented or that WQS will be met.

This TMDL report is organized with the following sections, addressing all components of a TMDL:

- **Problem Statement** describes the impairment(s) to be addressed by these TMDLs (Section 2)
- **Setting** presents the physical conditions in and around Arizona’s Hg-impaired waterbodies that influence pollutant loading conditions (Section 3)
- **Water Quality Standards and Numeric Endpoint Targets** identifies the applicable designated uses and criteria that are used for data assessment and TMDL calculations (Section 4)
- **Data Evaluation** presents a review of available water quality and fish tissue data, including a comparison to applicable criteria (Section 5)
- **Source Assessment** identifies potential sources of the pollutants of concern (Section 6)
- **Technical Approach** presents the range of approaches and the selected approach for TMDL development (Section 7)
- **Linkage Analysis** describes the methodology and analyses conducted to calculate the relationship between pollutant sources and receiving water conditions (Section 8)

- **TMDL Development** presents the loading capacity and allocations, the identified margin of safety (MOS), and seasonality and critical conditions (Section 9)
- **Implementation Planning** describes the regulatory and non-regulatory mechanisms by which the relevant stakeholders may achieve compliance with the TMDL allocations (Section 10)
- **Public Participation** describes the activities undertaken to ensure adequate participation in the TMDL development process by members of the public and any significant comments on the TMDL from members of the public (Section 11)

The TMDL document attempts to provide a plain language summary and salient results of a series of complex technical analyses. Full details of those analyses are provided in the technical support document, *Arizona Statewide Mercury TMDL Development: Technical Support Appendix (Tetra Tech, 2024)*, which is included as an Appendix to this report and is hereafter referred to as the 'Technical Support Appendix'.

Section 2 Problem Statement

There are 31 waterbodies located throughout the state of Arizona that are listed as impaired due to Hg and/or MeHg (ADEQ, 2024). These waterbodies (enumerated in Table 1 and mapped in Figure 22) were first listed as impaired between 1996 and 2024. These pollutant parameters have caused or contributed the designated uses not being met (Table 1).

The 31 Hg-impaired waterbodies are listed due to dissolved Hg levels exceeding Arizona WQS for the designated use of aquatic and wildlife warm water species (A&W) (2.4 µg/L acute, 0.01 µg/L chronic) and/or MeHg concentrations in fish tissue exceeding Arizona criteria for fish consumption (FC) (0.3 mg MeHg/kg). Fish tissue Hg contamination in these waterbodies, spanning streams, lakes, and reservoirs, predominantly stems from MeHg bioaccumulation in fish tissue.

Hg is a naturally occurring element. Its distribution in the environment is the result of both natural and anthropogenic processes. Hg occurs in both inorganic (as elemental Hg or ionic salts) and organic forms (predominantly MeHg). Elemental Hg is present in gaseous form and is transported worldwide through the atmosphere. MeHg is created from inorganic Hg by bacterial activity and is the form that bioaccumulates in the food chain, leading to human exposure through fish consumption. Figure 1 provides a simple schematic illustrating the major chemical transformations and transport pathways of Hg in an aquatic environment, including atmospheric deposition of inorganic Hg (Hg(II)), its reduction to volatile elemental Hg (Hg(0)), and the critical methylation into bioaccumulative MeHg (Missouri DNR, 2001).

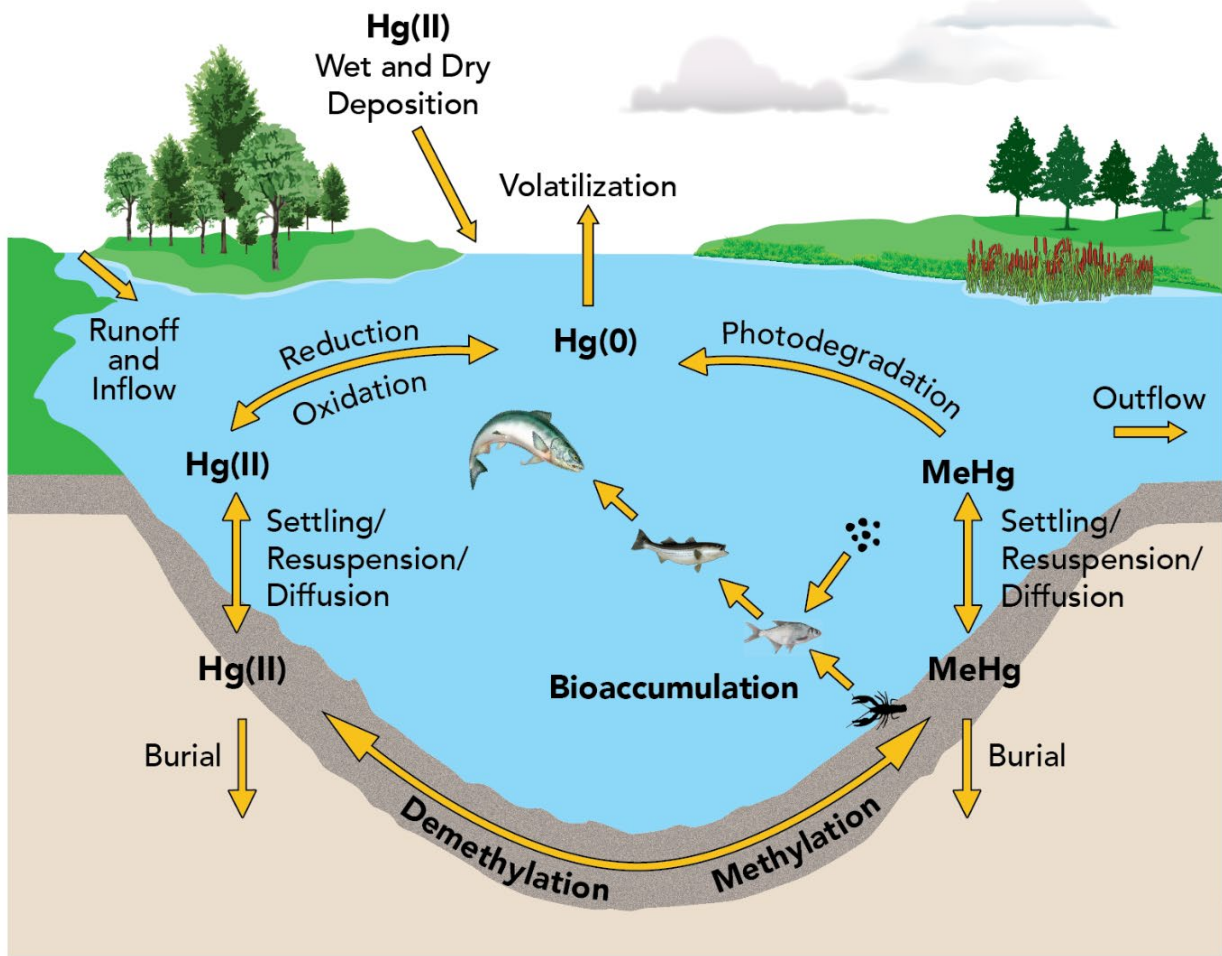


Figure 1. Schematic of mercury cycling in aquatic environment (Missouri Department of Natural Resources, 2021).

Hg in Arizona's impaired waters originates from many sources. The most important contributor of new Hg loads comes from atmospheric deposition to land and water. Hg is also present naturally, especially in areas of igneous geology such as those found in Arizona's mountain ranges. Historic mining activities are an important source of legacy Hg loading in these areas, especially from those established in the late 19th century. Some mines were developed directly for Hg, while others inadvertently released Hg associated with gold and silver ores. More importantly, the historic method of extracting gold and silver from raw ore used Hg amalgamation to concentrate the target metal – a process that often resulted in large-scale emissions and spills of Hg. Much of the Hg released by historic mining operations is believed to be stored in bottom deposits (stream beds and alluvial soils) and is subject to remobilization by storm erosion and/or human disturbance (Holloway *et al.*, 2009). Therefore, there are three main sources of Hg: atmospheric deposition, historic mining, and local geology.

Other sources of Hg loading include industrial and municipal permitted wastewater discharges, historic unregulated waste disposal sites, and urban stormwater. Of the 32 impairments across 31 waterbodies, all are affected by atmospheric deposition of Hg and most are potentially

affected by known legacy hardrock mining sites. Other sources, where known, are addressed on a site-by-site basis.

Table 1. Impaired Waterbody, Pollutant, Uses, and Causes of Impairment.

Waterbody Assessment Unit and Name	Pollutant	Impaired Uses	Year Listed	Key Pollutant Sources
15050301-1070 Peña Blanca Lake	Hg	Aquatic & Wildlife (warm water)	1996	Atmospheric deposition; Natural geology; Legacy mining and mine wastes; Historic bottom deposits; Permitted industrial and municipal point sources
	MeHg	Fish Consumption	1996	
15050304-0080 Arivaca Lake	MeHg	Fish Consumption	1996	
15020015-0890 Lake Mary (Lower)	MeHg	Fish Consumption	2002	
15020015-0900 Lake Mary (Upper)	MeHg	Fish Consumption	2002	
15020008-0820 Long Lake	MeHg	Fish Consumption	2004	
15020008-1430 Soldiers Annex Lake	MeHg	Fish Consumption	2004	
15020008-1440 Soldiers Lake	MeHg	Fish Consumption	2004	
15020001-0850 Lyman Reservoir	MeHg	Fish Consumption	2004	
15030204-0040A Alamo Lake	MeHg	Fish Consumption	2004	
15050301-1040 Parker Canyon Lake	MeHg	Fish Consumption	2004	
15060106A-0250 Canyon Lake	MeHg	Fish Consumption	2004	
15060103-1240 Roosevelt Lake	MeHg	Fish Consumption	2008	
15070102-1100 Lake Pleasant	MeHg	Fish Consumption	2008	
14070006-1130 Lake Powell	MeHg	Fish Consumption	2010	

15020010-0180 Black Canyon Lake	MeHg	Fish Consumption	2010	Atmospheric deposition; Natural geology; Legacy mining and mine wastes; Historic bottom deposits; Permitted industrial and municipal point sources
15060105-004 Tonto Creek	MeHg	Fish Consumption	2010	
15060105-006 Tonto Creek	MeHg	Fish Consumption	2010	
15060105-008 Tonto Creek	MeHg	Fish Consumption	2010	
15060105-009 Tonto Creek	MeHg	Fish Consumption	2010	
15060105-011 Tonto Creek	MeHg	Fish Consumption	2010	
15060105-013B Tonto Creek	MeHg	Fish Consumption	2010	
15060106A-0070 Apache Lake	MeHg	Fish Consumption	2016	
15060203-0110 Bartlett Lake	MeHg	Fish Consumption	2016	
15020001-0150 Becker Lake	MeHg	Fish Consumption	2017	
15020005-1360 Scott Reservoir	MeHg	Fish Consumption	2018	
15020010-1670 Willow Springs Lake	MeHg	Fish Consumption	2018	
15010004-1340 Santa Fe Reservoir	MeHg	Fish Consumption	2020	
15070102-0630 Horsethief Lake	MeHg	Fish Consumption	2020	
15050100-1662 Devils Canyon Creek	Hg	Aquatic & Wildlife (warm water)	2021	
15050100-012B Mineral Creek	Hg	Aquatic & Wildlife (warm water)	2021	
15050301-1050 Patagonia Lake	MeHg	Fish Consumption	2024	

This TMDL reflects a statewide approach to fish tissue and water column contamination of Hg and MeHg impairments in waterbodies throughout Arizona. This strategy was chosen for two main reasons.

First, with 31 impaired waterbodies included in this TMDL document, consolidating the TMDL development process allows the state to more efficiently allocate resources by addressing multiple waterbodies in a single report, rather than producing 31 individual reports with overlapping content related to Hg sources, cycling, and MeHg bioaccumulation. This approach minimizes time demands and redundant efforts while still ensuring that each TMDL is scientifically sound and defensible.

Second, many Hg sources, such as atmospheric deposition, can be more effectively analyzed at a broader geographic scale rather than at the individual watershed level, reducing duplicative work and lowering associated costs. By addressing all Hg-impaired waterbodies collectively, ADEQ can better identify future sampling needs and restoration opportunities across all affected systems, thereby improving statewide water quality management and restoration planning.

By approaching the TMDL with these reasons in mind, ADEQ can also efficiently add additional waterbodies to the TMDL if/when an Hg or MeHg impairment is identified in a waterbody not currently listed. Additional testing of fish tissue and water may yield additional impairments.

Arizona has previously developed TMDLs that were EPA-approved for seven of the listed waterbodies — Assessment Units 15050301-1070 (Peña Blanca Lake; ADEQ, 1999b), 15050304-0080 (Arivaca Lake; ADEQ, 1999a), 15020015-0890 (Lake Mary [Lower]), 15020015-0900 (Lake Mary [Upper]), 15020008-0820 (Long Lake), 15020008-1430 (Soldiers Annex Lake), and 15020008-1440 (Soldiers Lake; ADEQ, 2010). This Statewide Mercury TMDL will replace these earlier TMDLs to update them with current data and methods.

Note that Assessment Unit 14070006-1130 (Lake Powell) is a special case. Arizona has not sampled fish tissue MeHg concentrations in Lake Powell. However, Lake Powell is a shared waterbody between Utah and Arizona, and Utah documented elevation MeHg concentrations in striped bass within the lake. In reviewing Arizona's 2018 § 303(d) list, EPA indicated that Arizona should list its portion of Lake Powell as impaired based on Utah's data.

The total watershed drainage area of Lake Powell totals about 276,135 km². It encompasses portions of Utah, Colorado, Wyoming, and New Mexico and includes significant gold and silver mining areas. The Arizona portion of the watershed (15,410 km²) constitutes only 5.6 percent of the total drainage area. Reducing Hg loading to Lake Powell will require cooperation across multiple states and multiple EPA regions. Therefore, a full TMDL for Lake Powell will not be calculated as part of the Arizona Statewide Mercury TMDL.

In lieu of a full Hg TMDL for Lake Powell, ADEQ estimated the reduction in Hg loading needed to meet the median Arizona MeHg fish tissue target concentration of 0.3 mg/kg. This reduction estimate can be used to guide Hg LAs within Arizona's portion of the Lake Powell drainage area.

Section 3 Setting

Arizona's unique geography and geology present a complex environment for addressing Hg pollution in its waterbodies. The state spans a range of landscapes, from lowland desert basins to high-elevation mountain ranges, with ecosystems influenced by natural geological formations and human activities. This variation is reflected in Arizona's waterbodies, several of which are listed as impaired by Hg or MeHg, spanning diverse landscapes and settings across the state's

varied geography, as shown in Figure 2. Hg is a naturally occurring element in the environment, but its bioaccumulation in fish tissue presents significant health risks to both wildlife and humans.

This Statewide Mercury TMDL effort addresses 31 Hg-impaired lakes^a and streams across Arizona, identified through water quality and fish tissue monitoring (Figure 2). These waterbodies, located within several major drainage systems, such as the Colorado River Basin and the Gila River Basin, are the focus of the TMDL analysis. Hg impairments are primarily the result of elevated fish tissue Hg levels, with some waterbodies also showing elevated Hg concentrations in water and sediment.

The Hg-impaired waterbodies, listed with their corresponding Assessment Unit IDs (Table 1), have been mapped and categorized to ensure targeted remediation efforts.

The Statewide Mercury TMDL leverages both historical and recent Hg and MeHg data to understand the transport and fate of Hg in the state's waterbodies. By focusing on the interaction between land cover, geology, and hydrological processes, the TMDL aims to comprehensively determine the maximum pollutant load that each Hg-impaired waterbody under Arizona's jurisdiction can receive while still meeting WQS, and to identify the necessary reductions from various sources to help restore these waterbodies' designated uses.

^a *The reference to lakes includes both lakes and reservoirs.*

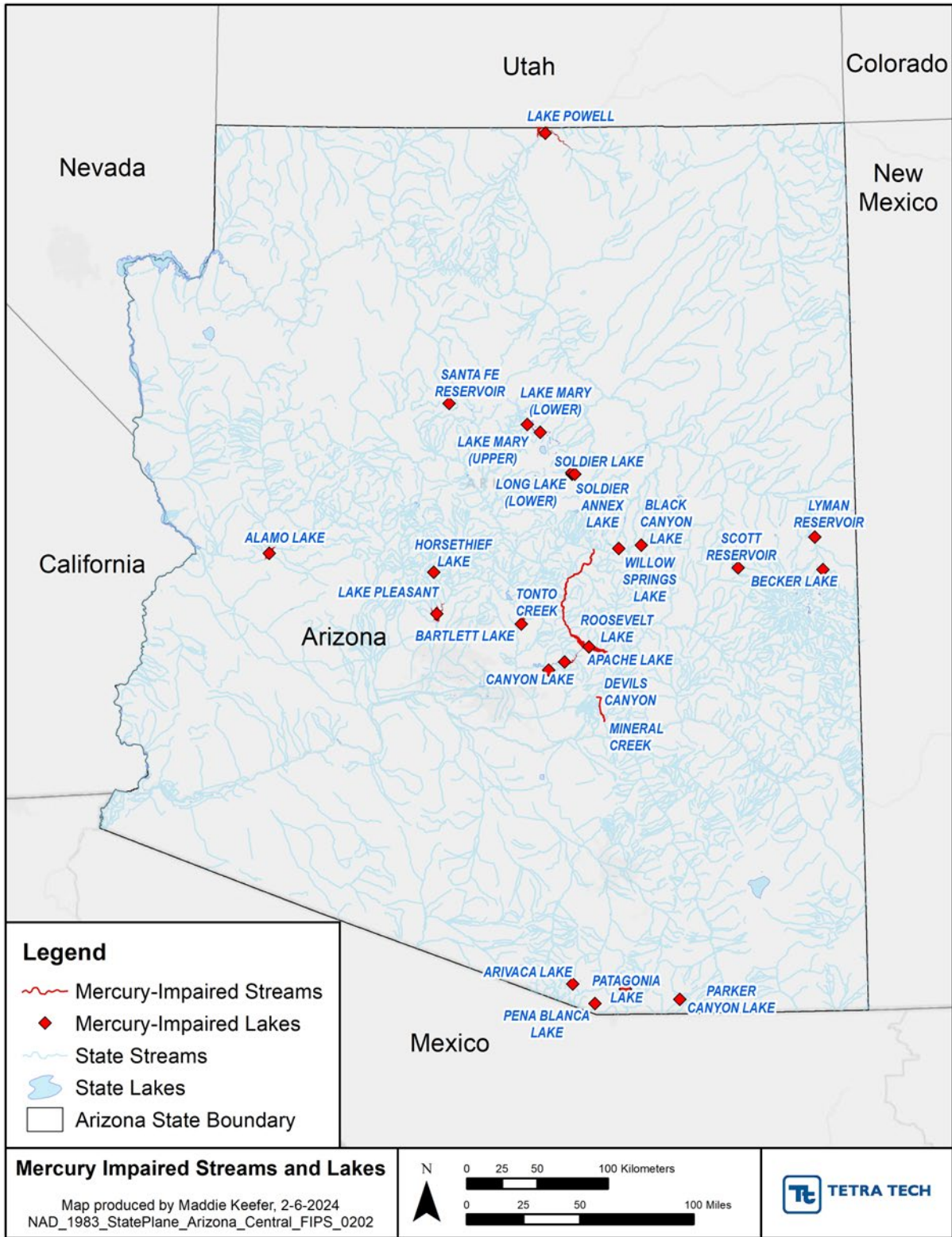


Figure 2. Map of Mercury-Impaired Waters Included in the Statewide TMDL Analysis.

3.1 Geology and Topography

Geologically, Arizona is characterized by mineral-rich formations, particularly along a northwest-to-southeast axis of mountainous terrain with igneous geology, where precious metals such as gold and silver are found. As shown in Figure 2, Hg impairments are notably absent in the lowland sedimentary geology of northern and southwestern Arizona.

As described in Section 6, the technical analyses for this TMDL are built upon the USGS SPATIally Referenced Regression on Watershed Attributes (SPARROW) and Water Balance Model (WBM) products. These models incorporate high resolution coverages of the topography and stream network of Arizona from the National Hydrography Dataset (NHD). SPARROW predictions of water yield and sediment erosion and transport are combined with coverages of geologic characteristics and mining activity to develop estimates of nonpoint source loading of Hg.

3.2 Climate

Arizona's climate ranges from arid to semi-arid. NOAA (2022) provides the following summary of Arizona Climate: "Arizona encompasses diverse climates and topography. The deserts in the south are some of the hottest and driest areas of the country, while the higher terrain of the Colorado Plateau in the northeast has a cooler climate, with cold winters and mild summers. The mountain ranges that run from the northwest to the southeast experience heavier precipitation and wide temperature variations."

"Annual average (1991–2020 normals) temperatures range from the 40s (°F) at the highest elevations in the mountains to the mid-70s (°F) in the lower elevations of the south. The southern deserts frequently experience summer temperatures between 105°F and 115°F. Extreme temperatures in Arizona range from a record high of 128°F at Lake Havasu City (June 29, 1994) to a record low of -40°F at Hawley Lake (January 7, 1971). The hottest year on record was 2017, with a statewide annual average temperature of 63.0°F, which is 3.3°F above the long-term (1895–2020) average."

Most of the Hg and MeHg impairments in Arizona are found in the higher elevation and wetter mountain regions that can support perennial streams and lakes and associated fisheries.

3.3 Land Cover

For the assessment of Hg sources, land uses/cover across Arizona are defined from the satellite-derived National Land Cover Database (NLCD; Dewitz, 2023). NLCD is a 30-meter resolution raster developed for the contiguous United States and Alaska by the Multi-Resolution Land Characteristics Consortium. A land use/cover analysis was completed for the state using 2021 NLCD data. Figure 3 and Table 2 show the distribution of Arizona land cover across the 16 NLCD classes (excluding unclassified).

NLCD's change index summarizes NLCD land cover change into 11 change classes. These classes are intended to communicate thematic change impact in an easy-to-visualize format. Figure 44 displays the NLCD land cover change index across the state of Arizona. Throughout most of the rural parts of the state, no significant land change has been seen in the period from 2001 to 2021. However, some areas of the state have seen changes in herbaceous rangeland, shrub/scrub, forest, and urban/developed land cover.

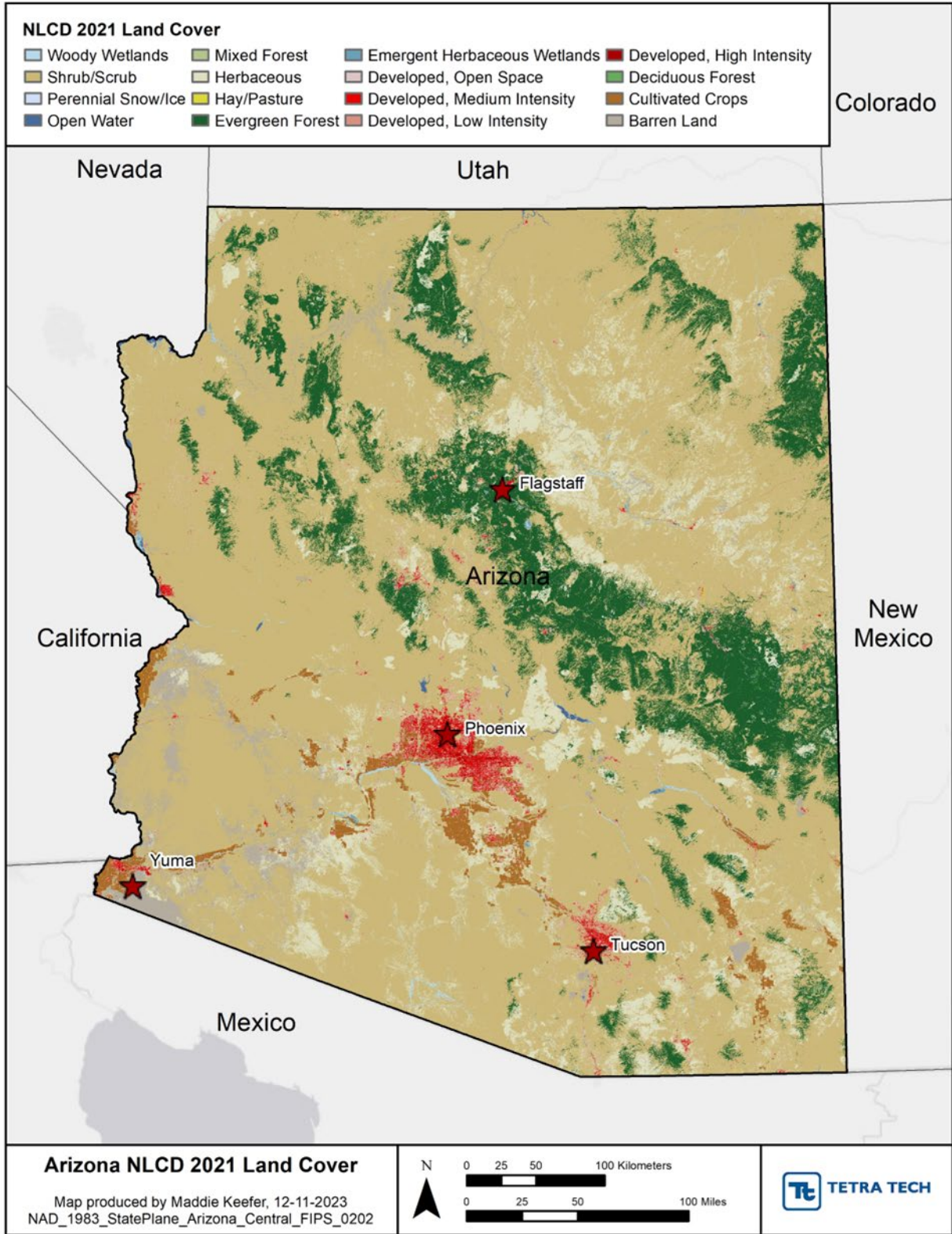


Figure 3. Arizona Land Use/Cover from NLCD 2021 (Dewitz, 2023).

Table 2. Areal Extent of Land Use Categories in Arizona based on NLCD 2021.

Land use/cover	Land use area (acres)	Land use area (km ²)	Percent of AZ
Shrub/Scrub	51,078,960	206,710	70.0%
Evergreen Forest	9,376,019	37,944	12.9%
Herbaceous	6,969,294	28,204	9.6%
Barren Land	1,915,219	7,751	2.6%
Cultivated Crops	1,195,371	4,838	1.6%
Developed, Open Space	724,115	2,930	1.0%
Developed, Low Intensity	504,024	2,040	0.7%
Developed, Medium Intensity	493,235	1,996	0.7%
Woody Wetlands	262,387	1,062	0.4%
Developed, High Intensity	149,620	605	0.2%
Open Water	141,342	572	0.2%
Emergent Herbaceous Wetlands	95,040	385	0.1%
Hay/Pasture	26,669	108	0.0%
Deciduous Forest	22,955	93	0.0%
Mixed Forest	21,271	86	0.0%
Unclassified	1,336	5	0.0%
Perennial Snow/Ice	0	0	0.0%
Total land area:	72,976,858	295,328	100%

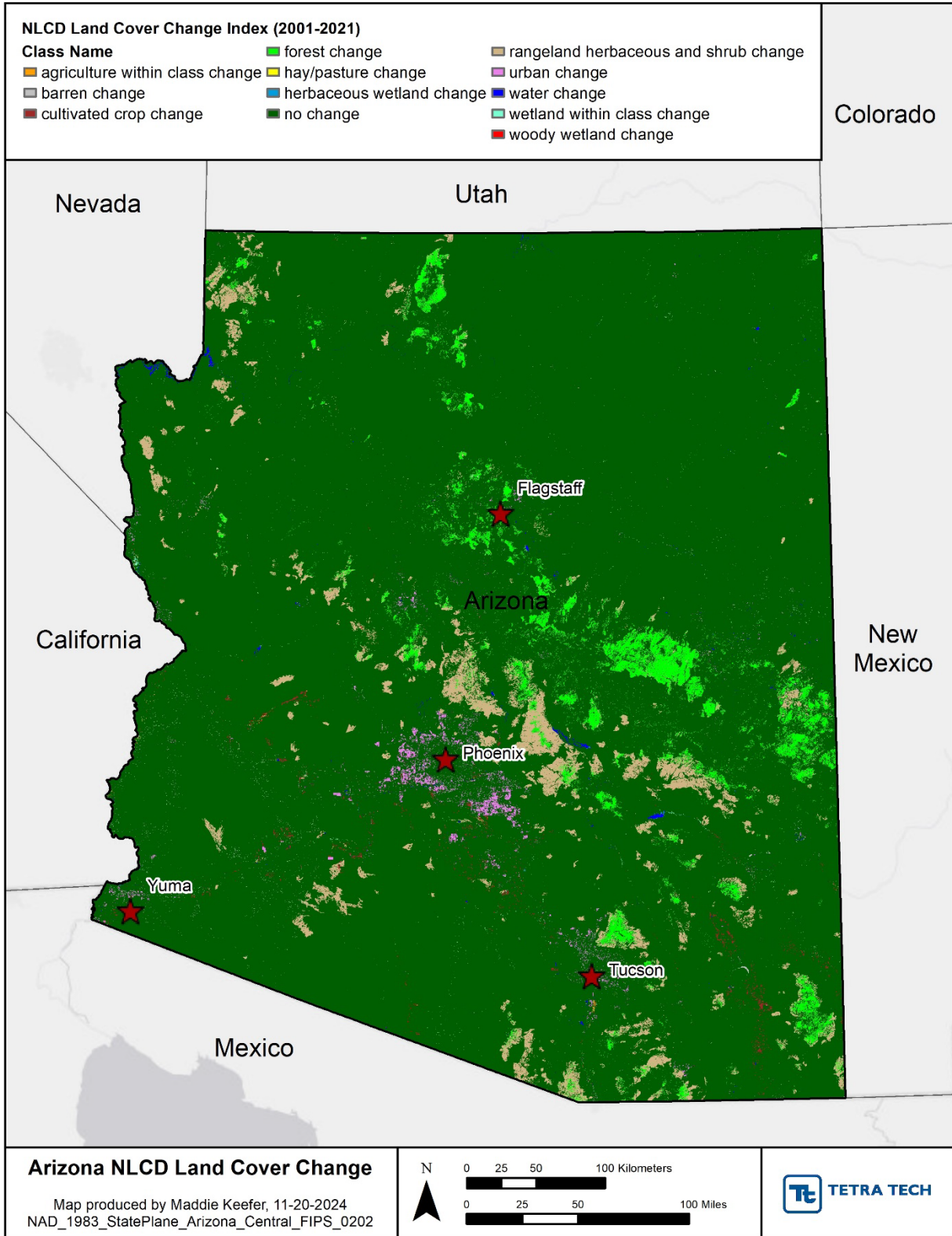


Figure 4. Arizona Land Cover Change from NLCD 2001-2021 (Dewitz, 2023).

Section 4 Water Quality Standards and Numeric Endpoint Targets

WQS are legal standards promulgated by the State of Arizona (Arizona Administrative Code Title 18, Chapter 11 [A.A.C. R18-11]). WQS are composed of three elements:

1. Designated Uses
2. Narrative and/or Numeric Water Quality Criteria
3. Antidegradation Policy

A numeric endpoint target identifies the specific goal or endpoint for the TMDL which signifies attainment of the waterbody's assigned designated uses. This section identifies the water quality standard(s) and designated use(s) applicable to the waterbodies included in the Arizona Statewide Mercury TMDL and identifies appropriate numeric endpoint targets for Hg or MeHg-impaired waterbodies.

4.1 Water Quality Standards

Arizona's Hg-impaired waterbodies are listed as impaired due to water column and fish tissue concentrations that do not support applicable designated uses for Aquatic & Wildlife (A&W) and Fish Consumption (FC).

4.1.1 Designated Uses

40 C.F.R. 131.3(f) defines designated uses as "those uses specified in the WQS regulations for each waterbody or segment whether or not they are being attained." The State has established nine designated uses in A.A.C. R18-11-104 (Table 3), as well as narrative and numeric criteria for protection of those uses. Waterbodies and their designated uses are listed in A.A.C. R18-11, Article 1, Appendix B. Waterbodies not listed in A.A.C. R18-11, Article 1, Appendix B, but which are a tributary to a listed waterbody, are assigned designated uses according to the Tributary Rule in R18-11-105. Designated uses applicable to the waterbodies subject to this TMDL are listed in Table 4.

Table 3. Designated Uses for Waterbodies in Arizona.

Designated Use	Description
Agricultural Irrigation (Agl)	The use of surface water for crop irrigation.
Agricultural Livestock Watering (AgL)	The use of surface water as a water supply for consumption by livestock.
Aquatic and Wildlife (cold water) (A&Wc)	The use of a surface water by animals, plants, or other cold-water organisms, generally occurring at an elevation greater than 5,000 feet, for habitation, growth, or propagation.
Aquatic and Wildlife (warm water) (A&Ww)	The use of a surface water by animals, plants, or other warm-water organisms, generally occurring at an elevation less than 5,000 feet, for habitation, growth, or propagation.

Designated Use	Description
Aquatic and Wildlife (ephemeral) (A&We)	The use of an ephemeral water by animals, plants, or other organisms, excluding fish, for habitation, growth, or propagation.
Aquatic and Wildlife (effluent-dependent water) (A&Wedw)	The use of an effluent-dependent water by animals, plants or other organisms for habitation, growth, or propagation.
Full-Body Contact (FBC)	The use of a surface water for swimming or other recreational activity that causes the human body to come into direct contact with the water to the point of complete submergence. The use is such that ingestion of the water is likely and sensitive body organs, such as the eyes, ears, or nose, may be exposed to direct contact with the water.
Partial-Body Contact (PBC)	The recreational use of a surface water that may cause the human body to come into direct contact with the water, but normally not to the point of complete submergence (for example, wading or boating). The use is such that ingestion of the water is not likely and sensitive body organs, such as the eyes, ears, or nose, will not normally be exposed to direct contact with the water.
Domestic Water Source (DWS)	The use of a surface water as a source of potable water. Treatment of a surface water may be necessary to yield a finished water suitable for human consumption.
Fish Consumption (FC)	The use of a surface water by humans for harvesting aquatic organisms for consumption. Harvestable aquatic organisms include, but are not limited to, fish, clams, turtles, crayfish, and frogs.

Table 4. Designated Uses of the Hg-Impaired Waterbodies in Arizona.

Waterbody Assessment Unit and Name	AgL	A&Wc	A&Ww	FBC	FC
15050301-1070 Pena Blanca Lake	✓		✓	✓	✓
15050304-0080 Arivaca Lake	✓	✓		✓	✓
15020015-0890 Lake Mary (Lower)	✓	✓		✓	✓
15020015-0900 Lake Mary (Upper)	✓	✓		✓	✓

Waterbody Assessment Unit and Name	AgL	A&Wc	A&Ww	FBC	FC
15020008-0820 Long Lake (Lower)	✓	✓		✓	✓
15020008-1430 Soldiers Annex Lake	✓	✓		✓	✓
15020008-1440 Soldiers Lake	✓	✓		✓	✓
15020001-0850 Lyman Reservoir	✓		✓	✓	✓
15030204-0040A Alamo Lake	✓	✓		✓	✓
15050301-1040 Parker Canyon Lake	✓		✓	✓	✓
15060106A-0250 Canyon Lake	✓		✓	✓	✓
15060103-1240 Roosevelt Lake	✓		✓	✓	✓
15070102-1100 Lake Pleasant	✓	✓		✓	✓
14070006-1130 Lake Powell	✓	✓		✓	✓
15020010-0180 Black Canyon Lake	✓		✓	✓	✓
15060105-004 Tonto Creek	✓		✓	✓	✓

Waterbody Assessment Unit and Name	AgL	A&Wc	A&Ww	FBC	FC
15060105-006 Tonto Creek	✓		✓	✓	✓
15060105-008 Tonto Creek	✓		✓	✓	✓
15060105-009 Tonto Creek	✓		✓	✓	✓
15060105-011 Tonto Creek	✓		✓	✓	✓
15060105-013B Tonto Creek	✓		✓	✓	✓
15060106A-0070 Apache Lake	✓		✓	✓	✓
15060203-0110 Bartlett Lake	✓	✓		✓	✓
15020001-0150 Becker Lake	✓	✓		✓	✓
15020005-1360 Scott Reservoir	✓	✓		✓	✓
15020010-1670 Willow Springs Lake		✓		✓	✓
15010004-1340 Santa Fe Reservoir	✓	✓		✓	✓
15070102-0603 Horsethief Lake	✓		✓	✓	✓
15050100-1662 Devils Canyon	✓		✓	✓	✓

Waterbody Assessment Unit and Name	AgL	A&Wc	A&Ww	FBC	FC
15050100-012B Mineral Creek	✓		✓	✓	✓
15050301-1050 Patagonia Lake	✓		✓	✓	✓

4.1.2 Water Quality Criteria

Arizona has promulgated WQS approved by EPA in 2016 applicable to Hg in water and fish tissue in A.A.C. R18-11, Article 1, Appendix A. Table 5 summarizes the water quality criteria.

Table 5. Applicable Water Quality Criteria for Hg.

Designated Use	Parameter	Criterion
AgL	Hg (total recoverable)	10 µg/L
A&Wc	Hg (dissolved)	2.4 µg/L (Acute) 0.01 µg/L (Chronic)
A&Ww	Hg (dissolved)	2.4 µg/L (Acute) 0.01 µg/L (Chronic)
A&We	Hg (dissolved)	5 µg/L (Acute)
A&Wedw	Hg (dissolved)	2.4 µg/L (Acute) 0.01 µg/L (Chronic)
FBC	Hg (total recoverable)	280 µg/L
PBC	Hg (total recoverable)	280 µg/L
DWS	Hg (total recoverable)	2 µg/L
FC	MeHg (in fish tissue) ^a	0.3 mg/kg

- a. *Fish tissue criteria are technically based on MeHg concentrations (USEPA, 2001a). However, because most fish tissue analyses measure THg, we use the term “fish tissue Hg concentrations” to refer to THg measurements throughout this text. In higher trophic level fish, Hg is predominantly present as MeHg, the form that bioaccumulates. Assessing impairments based on THg in fish introduces a small margin of safety, as it accounts for both MeHg and non-MeHg forms of Hg, even though MeHg has the capacity to bioaccumulate and is the more toxic form.*

4.3.1 Antidegradation Policy

The Antidegradation Policy promulgated in A.A.C. R18-11-107(B) states:

“Tier 1: The level of water quality necessary to support an existing use shall be maintained and protected. No degradation of existing water quality is permitted in a surface water where the existing water quality does not meet the applicable water quality standards.”

Tier 1 antidegradation protection applies to surface waters listed on the State’s § 303(d) list, including those covered under this TMDL, for the pollutant that resulted in the listing. Based on the above provision, the Antidegradation Policy prohibits any water quality degradation which would interfere with or prevent attainment with existing designated uses.

4.2 TMDL Numeric Endpoint Targets

Numeric targets are a required component of a TMDL. A numeric target is the quantitative value used to calculate the loading capacity and evaluate whether the applicable designated uses are attained. For total recoverable Hg or dissolved Hg, the numeric targets are the controlling (or lowest) numeric water quality criterion as specified in Table 5 for designated uses of the waterbody as listed in Table 4. The resulting TMDL numeric targets are shown in Table 6 for these waters that are only impaired for Hg in the water column.

Table 6. TMDL Numeric Targets for Hg in Water.

Waterbody	Pollutant	TMDL Numeric Target
15050100-012B (Mineral Creek)	Hg (dissolved)	0.01 µg/L (10 ng/L)
15050100-1662 (Devils Canyon)	Hg (dissolved)	0.01 µg/L (10 ng/L)

To protect the FC designated use ADEQ also specifies a fish tissue concentration target of 0.3 mg/kg MeHg. The fish tissue MeHg concentration is bioaccumulated within waterbodies and is not a loaded quantity. Therefore, to calculate a TMDL relative to FC use impairment it is necessary to translate the fish tissue target to a water column Hg concentration target, as described in Section 4.3.

4.3 Supplemental Criteria and Screening Values

Fish accumulate most of their MeHg through their diet, with direct absorption from water serving as a minor exposure pathway. The rate at which fish eliminate MeHg is considerably slower than the rate of uptake, allowing the compound to build up in their tissues (Laarman *et al.*, 1975; McKim *et al.*, 1976). In contrast, inorganic Hg is eliminated more quickly and does not persist in fish tissues (Hildebrand *et al.*, 1980a; Hildebrand *et al.*, 1980b). As a result, nearly all Hg present in fish tissue — often more than 95 percent in higher trophic level species — is in the form of MeHg (Eagles-Smith *et al.*, 2016; EPA, 1997). Consequently, total mercury (THg) measurements in fish tissues are generally considered a conservative estimate of MeHg content.

To assign water column targets to address impairments based on elevated fish tissue concentrations of MeHg it is necessary to establish a relationship between fish tissue concentrations and ambient Hg exposure concentrations. This was done (consistent with USEPA, 2001a and USEPA, 2010) through a bioaccumulation factor (BAF) analysis.

A BAF describes the relationship between Hg concentrations in fish (as mg of MeHg per pound of wet weight fish tissue) and Hg exposure concentrations in water (as mg Hg per L) as the ratio of the two measures. The BAF thus has units (after cancellation) of liters of water per kg of fish tissue. Multiplying the BAF times the exposure concentration (mg/L) yields an estimate of the fish tissue concentration (mg/kg).

BAFs can be calculated relative to dissolved MeHg in water, total MeHg in water, or total Hg in water. In theory, it would be most appropriate to calculate the Hg BAF as a ratio to dissolved MeHg in water as this is the form of Hg that bioaccumulates. There are, however, problems with this approach. First, dissolved MeHg concentrations in the environment tend to be extremely low, are often at or below practical quantitation limits, and are less frequently available than total recoverable Hg measurements. Second, the majority of MeHg that enters the food chain is created by bacterial activity from inorganic Hg within waterbodies and sediment under low oxygen conditions. Ultimate load sources from the land and atmosphere are primarily inorganic Hg and developing LAs/WLAs for total Hg thus requires a translator between total recoverable Hg concentration and MeHg.

For the Arizona Statewide Mercury TMDL, ADEQ thus developed BAFs relative to total recoverable Hg as the approach for which the best data support was available. Essentially this total Hg BAF combines the relationship between total Hg and MeHg in water with the relationship between MeHg in water and MeHg in fish.

Development of the BAFs is described in Section A-3.0 of the Technical Support Appendix. Fish tissue burdens of MeHg increase with age and size. They also tend to be higher at higher trophic levels — that is, fish that consume other fish will concentrate more MeHg in their bodies. The TMDL process thus focused on higher trophic level bass and catfish species and also adjusted or normalized fish tissue concentrations to a standard length typical of fish of a given species that are caught and consumed. The purpose of normalizing the data is to reduce bias caused by including extremely small or large individuals in the analysis. Analysis was done separately for standing waters (lakes and reservoirs) versus flowing waters (streams) as these two systems may have different food chain bioaccumulation pathways. The higher trophic level bass and catfish species were specifically selected due to their likely presence in all impaired waterbodies and where sample data was more plentiful. Other higher trophic level species, such as walleye and pike, were also considered for analysis, but due to their limited presence in Arizona waterbodies or less data availability the bass and catfish species will serve as surrogates for MeHg reductions needed in these other predatory species. Trout is also a commonly consumed fish in Arizona, but tend to have a lower MeHg burden than some of the other selected fish species. For relative concentrations of Hg in specific fish species see Figure 5 below^b.

^b *If interested in determining current fish advisories for individual species in specific waterbodies, information is available through Arizona Game and Fish website: <https://www.azgfd.com/fishing-2/fish-consumption-advisories/>*

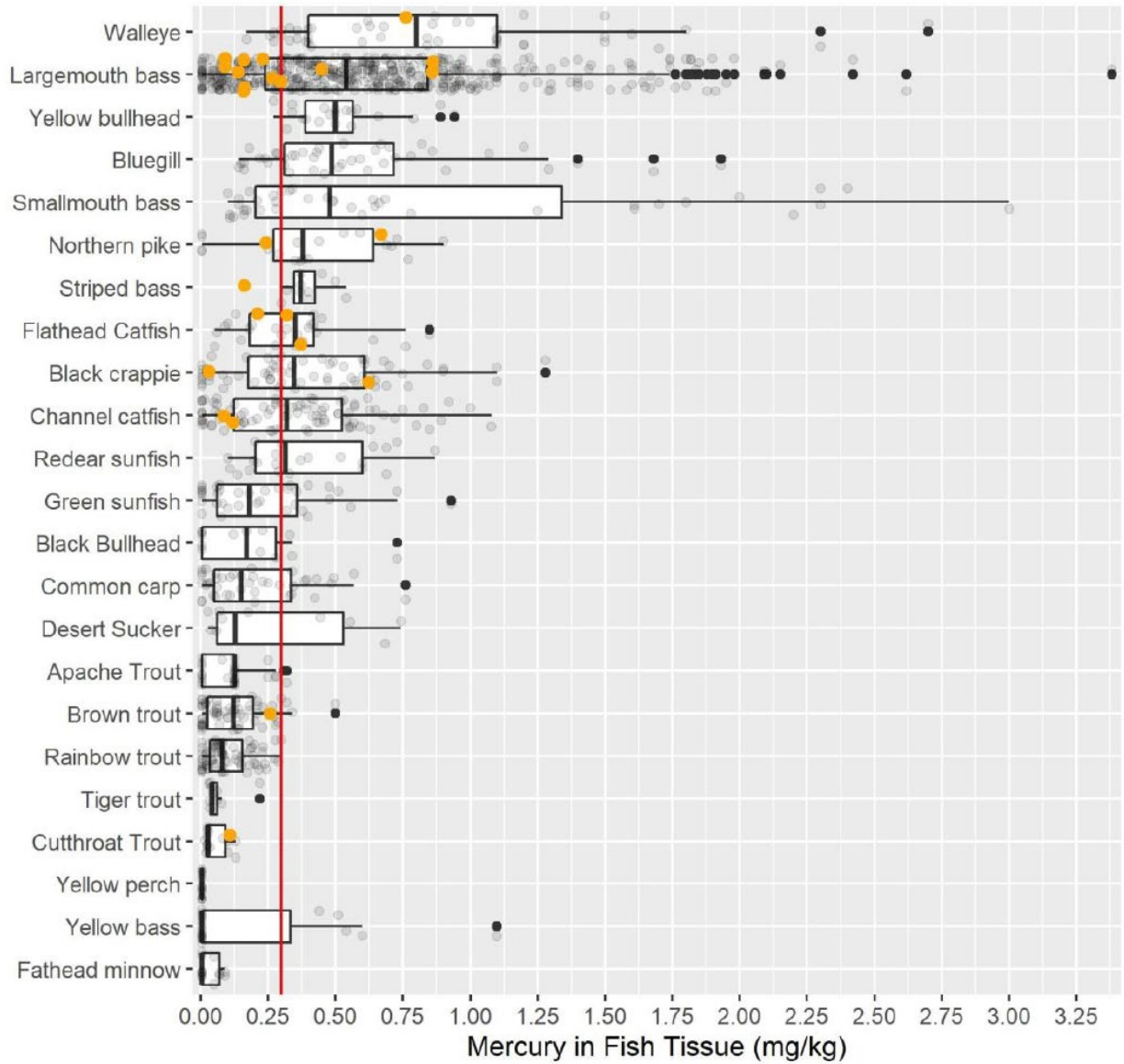


Figure 5. Hg in Arizona Fish Species.

BAFs for individual impaired water sites were calculated consistent with USEPA (2010) as the ratio of the median fish tissue concentration to the median water column exposure concentration (see section A-3.2 for data summaries). The use of the median helps avoid bias due to anomalous outliers in small samples. The overall statewide “aggregated” BAFs were then calculated, again consistent with USEPA (2010) as the geometric mean across all individual sites. The resulting THg BAF estimates are shown in Table 7. The table also shows BAFs calculated relative to total MeHg for comparison. Insufficient data above detection limits prevented calculation of BAFs relative to dissolved MeHg.

Once the BAF was calculated, the target water column concentration was calculated by dividing the fish tissue criterion (0.3 mg/kg) by the BAF and converting units. The higher the BAF the lower the resulting water concentration target will be. For lakes and reservoirs, we selected the average of the water column target estimates for channel catfish (CCF), flathead catfish (FHC), and largemouth bass (LMB) of 1.349 ng/L. This is slightly greater than the target calculated from LMB data alone of 1.346 ng/L. To be more protective of flowing waters, the limited data availability of stream sites with paired fish tissue and water column Hg data suggests it is more appropriate to use the most restrictive target (1.974 ng/L) estimated for channel catfish (Table 8). For more detailed information on the determination of the TMDL target concentrations see Section A-3.2 & A-3.3 in the Technical Support Appendix.

Table 7. Hg BAF Estimates.

Waterbody Type	Fish Species	# of Waterbodies with Data ^a	BAF (L/kg) for THg	BAF (L/kg) for MeHg	THg Target (ng/L)
Lake/Reservoir	Channel Catfish (CCF)	9	0.13 x 10 ⁶	3.80 x 10 ⁶	2.350
	Flathead Catfish (FHC)	2	0.86 x 10 ⁶	7.68 x 10 ⁶	0.350
	Largemouth Bass (LMB)	15	0.22 x 10 ⁶	2.87 x 10 ⁶	1.346
Stream	Channel Catfish (CCF)	1	0.15 x 10 ⁶	ND	1.974
	Flathead Catfish (FHC)	1	0.04 x 10 ⁶	ND	7.268
	Largemouth Bass (LMB)	1	0.04 x 10 ⁶	0.13 x 10 ⁶	8.068

a. For available data used, see Section A-3.2

Table 8. TMDL Supplemental Criteria for Total Recoverable Hg to Address Fish Consumption Impairments.

Waterbody Type	Pollutant	TMDL Numeric Target
Lakes and Reservoirs	Hg (total recoverable)	1.349 ng/L
Streams	Hg (total recoverable)	1.974 ng/L

Section 5 Data Evaluation

An important step in the TMDL development process is the review of existing water quality monitoring data. Examination of these data assists in defining the impairment that the TMDL will address and provides a basis for future implementation efforts by identifying potential sources through pattern analysis. This section provides a review of the available water quality, sediment quality, and fish tissue data in and around Arizona's 31 Hg-impaired waterbodies.

The water quality data compiled for Arizona's Statewide Mercury TMDL effort included extensive datasets covering streams, lakes, and reservoirs. These data were sourced from EPA's Water Quality Portal (WQP), which includes data from multiple sources including ADEQ, Arizona

Game and Fish Department, and U.S. Fish and Wildlife Service. The datasets contain Hg and MeHg concentrations for both water column and sediment samples, as well as fish tissue data critical for assessing MeHg bioaccumulation.

5.1 Water Quality Data – Streams and Lakes

For the surface water Hg monitoring efforts in Arizona’s streams and lakes, over 140,000 records of Hg data were initially compiled from impaired and unimpaired waters, covering THg, dissolved Hg, and MeHg concentrations. After screening the initial data compilation for reporting anomalies and inaccuracies, which are further described in the following paragraph, additional data organization and visualization were performed using R (R Core Team, 2023). Table 9 displays a summary table of available surface water Hg data that were obtained for the statewide TMDL analysis. Regarding water column observations of THg, the central tendencies are similar for lake/reservoir and stream data (Figure 6). Water column data from stream waterbody types display the largest variation, with many samples above the chronic criterion (10 ng/L) and some samples above the acute criterion (2,400 ng/L). For observations of MeHg in the water column, the concentrations are roughly 1.5 orders of magnitude smaller than water column THg observations. MeHg concentrations for lake/reservoir waterbodies are lower than stream waterbody values on average, with samples for stream waterbodies spanning the widest range of values as shown in Figure 7.

Table 9. Summary Statistics for Available Surface Water Hg Data.

Group	Parameter Form (units)	N	Min	Geomean	Median	MAD ^a	Max
Hg	Dissolved (ng/L)	1,547	0.025	1.103	1.08	0.83	938
	Suspended Particulate (ng/g)	57	5	22.502	20	15	5,685
	Total Particulate (ng/g)	325	0.772	53.649	50	27.8	2,000
	Total (ng/L)	1,479	0.035	3.245	2.5	1.2	3,100
MeHg	Dissolved (ng/L)	8	0.05	0.0651	0.0655	0.006	0.081
	Total Particulate (ng/g)	163	0.004	0.214	0.239	0.198	6.78
	Total (ng/L)	436	0.01	0.235	0.192	0.14	53

MAD = Median Absolute Difference

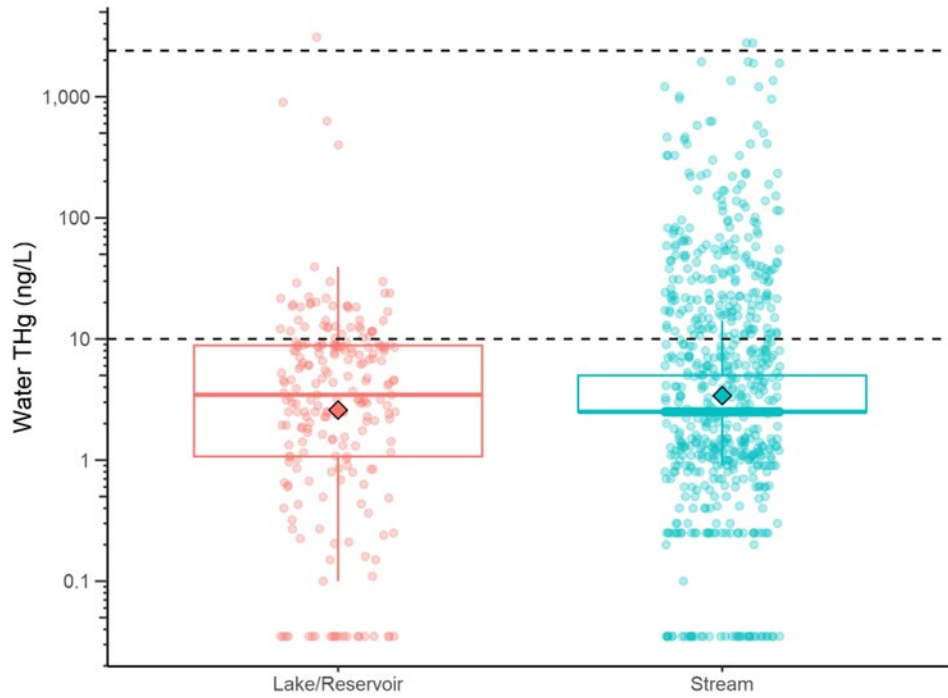


Figure 6. Boxplots of Water Column THg Concentrations by Waterbody Type. Horizontal dashed lines denote the EPA promulgated chronic and acute criteria for Hg in water for AZ (10 ng/L and 2,400 ng/L, respectively).

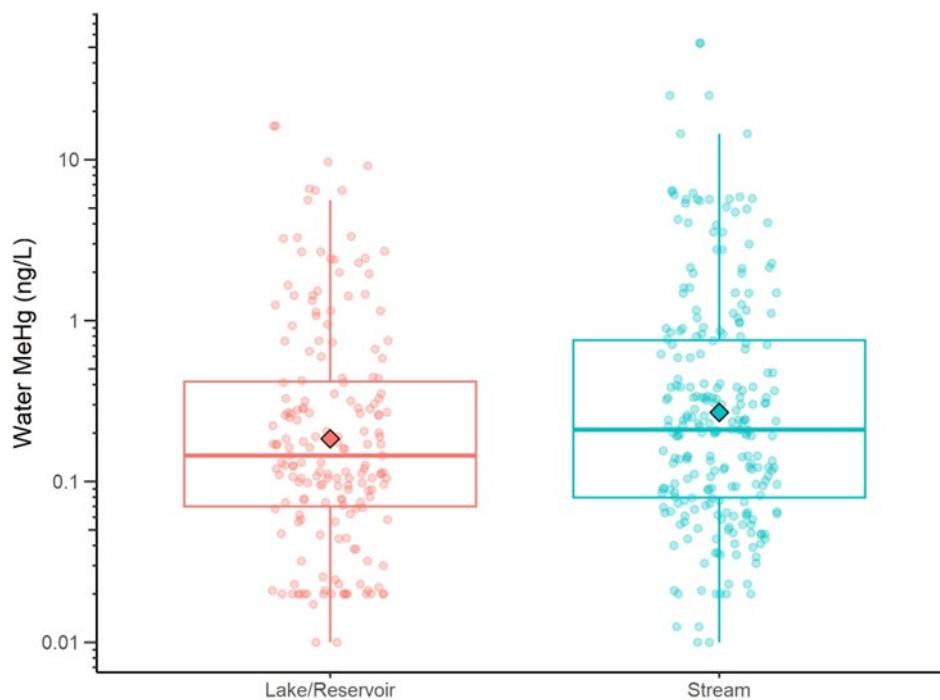


Figure 7. Boxplots of Water Column MeHg Concentrations by Waterbody Type. Top and bottom of the boxes denote the 75th and 25th percentiles. Thick horizontal line denotes the median. Vertical lines extend to “1.5 * (75th -25th percentile)”. Colored diamonds denote geomeans.

However, it is important to note certain anomalies in the historical Hg data, which affect the calculation of BAFs, MeHg ratios, and sediment potency factors. Early Hg data, for instance, sometimes contained reporting errors, such as incorrect units (e.g., mg/L instead of $\mu\text{g/L}$), leading to inflated THg concentrations. Additionally, some older datasets used high detection limit (DL) or high reporting limit (RL) methods, making it difficult to assess Hg concentrations accurately for the purposes of calculating key ratios. Many early analytical methods, like EPA Method 245.1, had detection limits around 200 ng/L, far above the typical ambient THg concentrations found in Arizona’s streams and lakes, which generally range between 1 and 50 ng/L. A more detailed discussion of these anomalies is provided in Addendum A of the Technical Support Appendix. To ensure accuracy in the analyses, historical Hg data that exhibited clear reporting anomalies or inaccuracies were excluded. Specifically, datasets with obvious unit errors (e.g., reporting mg/L instead of $\mu\text{g/L}$) or inflated THg values were omitted. Additionally, older datasets that used analytical methods with high detection limits, such as EPA Method 245.1, were disregarded. By excluding these erroneous or unreliable data points, the TMDL data analysis aimed to prevent inaccuracies in relevant calculations, ensuring a more precise and representative assessment.

For future analyses, EPA Method 1631 for THg and Method 1630 for MeHg, both of which offer lower RLs ($< 1 \text{ ng/L}$), are preferred due to their precision and reliability. These methods, implemented after 2001, provide much-needed accuracy for calculating Hg ratios. Certain other methods, like USGS Method CV018, EPA 245.7, and SW 846, which use cold vapor atomic absorption (CVAA), are also acceptable when they achieve DLs below 5 ng/L. However, the

inclusion of early data that do not meet these standards must be approached with caution, as outlined in Addendum A of the Technical Support Appendix.

5.2 Water Quality Data – Wells and Groundwater

Groundwater plays a role in Hg transport, primarily by transmitting atmospherically deposited Hg to surface waters, particularly in shallow subsurface flows. However, for the purposes of the statewide TMDL analysis, groundwater was not included as a separate pathway. This is because the SPARROW model for the Southwestern United States (Section 7.2) integrates shallow groundwater contributions with surface runoff, and seepage from mining areas is accounted for in the estimates of Hg loading from alluvial areas. The conceptual model for arid, mountainous regions with sparse vegetation suggests that most surface water flow results directly from precipitation runoff, with groundwater seepage being a minor factor except in specific locations, such as the Upper Verde River. Additionally, the available data on Hg in groundwater predominantly comes from deeper irrigation wells, which do not typically reflect the conditions of shallow groundwater interacting with surface waters. Therefore, this pathway is implicitly covered within the model's overall framework for estimating Hg transport.

5.3 Sediment Data

Sediment samples are an important component of the statewide analysis dataset, providing insights into Hg and MeHg accumulation in streambeds and lakebeds. Around 620 sediment samples from impaired and unimpaired waterbodies were available, with total Hg in bed sediments varying from 5 ng/g to 5,800 ng/g (Table 10). Sediment MeHg data, although fewer in number (approximately 160 samples), showed concentrations up to 6.78 ng/g. This information is essential for understanding Hg cycling in aquatic environments and its potential for bioavailability and bioaccumulation.

For this TMDL, these data were used primarily to support characterization of Hg concentrations in bed sediments and particulates, in the development of sediment-associated Hg potency factors, and assistance for near-channel and floodplain source characterization. Sediment data were not used directly to calculate loading capacities, but informed key assumptions related to Hg transport and legacy source behavior in the watershed modeling framework.

Table 10. Summary Statistics for Available Sediment Hg Data.

Group	Parameter Form (units)	N	Min	Geomean	Median	MAD ^a	Max
Hg	Bed Sediment Particulate (ng/g)	120	5	41.305	40	20	5,800
	Suspended Particulate (ng/g)	13	5	67.484	40	35	5,685
	Total (mg/L)	3	5.00E-05	6.30E-04	1.00E-04	5.00E-05	0.05
	Total Particulate (ng/g)	326	0.5695	47.754	50	30.03	2,000
MeHg	Total Particulate (ng/g)	159	0.004	0.215	0.239	0.178	6.78

MAD = Median Absolute Difference

5.4 Fish Tissue Data

ADEQ collects fish tissue to determine risks to human health from pollutants such as Hg and pesticides. Once Hg contaminants reach surface waters, they may be available for bioaccumulation, either directly or through aquatic food webs, and may accumulate in fish and shellfish tissues. Results from fish tissue monitoring serve as an important indicator of further contamination of sediments and surface water.

Available fish tissue data span nearly three decades, from 1995 to 2022, covering 1,458 fish samples across Arizona’s waters. These records are critical for assessing the risks posed to human health from Hg exposure through fish consumption. The fish tissue dataset focuses on several species of interest, including largemouth bass (LMB), flathead catfish (FHC), and channel catfish (CCF), which are higher on the food chain and more likely to be consumed. Many measurements are also reported for Trophic Level 3 species (bluegill, redear sunfish, and green sunfish), which are grouped as sunfish (SUN), are also included for comparison. MeHg concentrations in fish tissue frequently exceeded Arizona’s fish tissue criterion of 0.3 mg/kg, as shown in Table 11 and Figure 8, with LMB showing a particularly high exceedance rate of 68.8 percent. The tissue samples were primarily collected from lakes, where bioaccumulation risk is typically higher due to more stable water conditions. These samples were collected from both impaired and unimpaired waterbodies, as the inclusion of non-impaired waters is important for characterizing the full range of Hg exposure conditions and for developing stable bioaccumulation factors (BAFs). This approach is consistent with USEPA (2010) guidance and other statewide Hg TMDLs, where statewide datasets are used to develop exposure-response relationships rather than relying solely on impaired reaches.

Table 11. Sample and Exceedance Counts by Species of Interest, Based on the Fish Tissue MeHg Criterion of 0.3 mg/kg.

Species of Interest Common Name	Binomial Nomenclature	Count of Fish Tissue Samples (N)	Number of Tissue Samples Exceeding 0.3 mg/kg Criterion	Number of Tissue Samples Not Exceeding 0.3 mg/kg Criterion	Percent Exceed
Channel Catfish (CCF)	<i>Ictalurus punctatus</i>	109	50	59	45.9%
Flathead Catfish (FHC)	<i>Pylodictis olivaris</i>	34	17	17	50.0%
Largemouth Bass (LMB)	<i>Micropterus salmoides</i>	541	372	169	68.8%
Sunfish (SUN)	<i>Lepomis macrochirus</i> ; <i>Lepomis microlophus</i> ; <i>Lepomis cyanellus</i>	96	55	41	57.3%

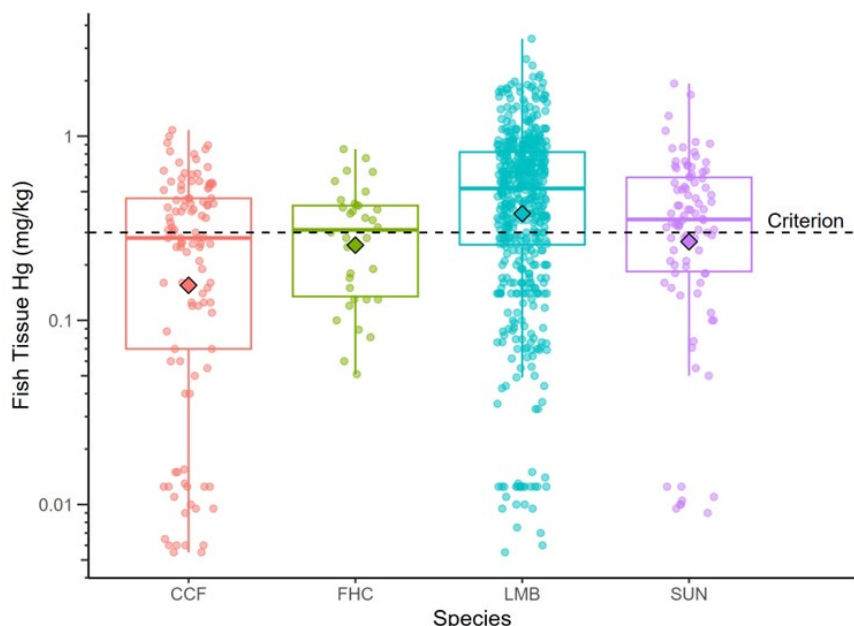


Figure 8. Boxplots of Fish Tissue MeHg Concentrations by Species. The horizontal dashed line denotes the Arizona fish tissue criterion (0.3 mg/kg).

5.5 Summary of Findings

This Statewide Mercury TMDL assessment encompasses 31 Hg-impaired waterbodies across Arizona, utilizing available monitoring data for surface water, sediment, and fish tissue. The data evaluation and subsequent TMDL analyses integrate these datasets to assess the extent and patterns of impairment across these waterbodies, focusing on water column THg and fish tissue MeHg concentrations.

From the available surface water monitoring data, Hg concentrations in streams and lakes show exceedances of both chronic (10 ng/L) and acute (2,400 ng/L) Arizona Hg criteria. Both dissolved Hg and THg concentrations demonstrate substantial variability across the state, with streams showing a wider range of Hg levels compared to lakes. MeHg concentrations, which are typically an order of magnitude lower than total Hg, still display notable ranges, particularly in stream environments. This spatial variation suggests that streams may be more prone to Hg mobilization, especially during storm events or in areas with legacy mining impacts.

Sediment data, drawn from approximately 620 samples, further underscores the variability of Hg concentrations across the state. THg in bed sediments ranges from 5 ng/g to 5,800 ng/g, with some samples demonstrating the potential for significant long-term Hg accumulation in streambeds and lakebeds. MeHg, though present in fewer sediment samples, also exhibits concentrations up to 6.78 ng/g, reinforcing the potential for bioavailability in aquatic environments.

The fish tissue monitoring dataset, spanning nearly 30 years, highlights a pervasive issue of MeHg bioaccumulation. Exceedances of the Arizona fish tissue MeHg criterion (0.3 mg/kg) were

widespread, particularly among higher trophic-level species such as LMB, where 68.8 percent of samples exceeded the criterion. These findings indicate a direct risk to human health from fish consumption, with lakes showing particularly high rates of MeHg bioaccumulation due to stable water conditions.

While some Hg-impaired waterbodies in Arizona with elevated fish tissue concentrations, such as Scott Reservoir and Horsethief Lake, lack water column Hg, MeHg, and total suspended solids (TSS) data, these gaps were addressed through various strategies to ensure the Statewide Mercury TMDL analysis remained robust. For waterbodies without direct water column data, ADEQ leveraged surrogate data and modeling approaches. For instance, the SPARROW model was employed to estimate Hg transport and concentrations based on landscape characteristics and sediment delivery. BAFs were then used to back-calculate the corresponding water column concentrations. Formula specifics can be found in the Technical Appendix, Sections A-3.2 & A-3.3. These strategies ensured that all waterbodies received meaningful analyses despite the absence of complete monitoring datasets.

Section 6 Source Assessment

A key component of a TMDL evaluation is the determination of known and potential sources of contamination to the watershed. Source assessment analyses are generally used to evaluate the type, magnitude, timing, and location of pollutant loading to a waterbody (EPA, 1999). Source assessment methods vary widely with respect to their applicability, the ease of use, and acceptability. This section presents potential sources of Hg loading in Arizona that may contribute to pollutant concentrations in Hg-impaired watersheds, as well as the mechanisms by which Hg can reach the impaired waterbodies, both of which can be useful in determining applicable implementation efforts.

Contaminant sources include both point sources and nonpoint sources. Point sources of pollutants are regulated under National Pollutant Discharge Elimination System (NPDES) permits. In Arizona, ADEQ has program approval from the EPA to administer the NPDES permitting program, which is known as Arizona Pollutant Discharge Elimination System (AZPDES) in the state. Point sources may include discharges from municipal or industrial wastewater treatment plants (WWTPs), AZPDES-regulated sources of urban stormwater runoff called Municipal Separate Stormwater Sewer Systems (MS4s), and other AZPDES discharges. Nonpoint sources are pollutant sources that reach the receiving water via indirect mechanisms not regulated under the AZPDES program, such as atmospheric deposition, unregulated stormwater runoff, geologic sources, groundwater, and legacy mine tailings piles. The distribution of significant sources of Hg load to the Hg-impaired waterbodies are summarized in Table 12. This table is derived from Section A-6.0 and Table A-6-1 of the Technical Support Appendix. Hg loads to waterbodies are estimated using SPARROW. Note that many of the watersheds are nested so that one source may contribute Hg load to more than one waterbody.

Table 12. Point and Nonpoint Sources of Hg Load.

Waterbody (WBID)	Natural geology	Legacy mines and mine waste	Atmospheric deposition	Permitted point sources
Peña Blanca Lake (AZL15050301-1070)	X	X	X	

Parker Canyon Lake (AZL15050301-1040)			X	
Patagonia Lake (AZL15050301-1050)	X	X	X	X
Arivaca Lake (AZL15050304-0080)			X	
Scott Reservoir (AZL15020005-1360)	X	X	X	
Canyon Lake (AZL15060106A-0250)	X	X	X	X
Apache Lake (AZL15060106A-0070)	X	X	X	X
Bartlett Lake (AZL15060203-0110)	X	X	X	X
Lake Pleasant (AZL15070102-1100)	X	X	X	X
Becker Lake (AZL15020001-0150)	X	X	X	
Horsethief Lake (AZL15070102-0630)	X		X	
Willow Springs Lake (AZL15020010-1670)	X		X	
Black Canyon Lake (AZL15020010-0180)	X		X	
Alamo Lake (AZL15030204-0040A)	X	X	X	X
Lyman Reservoir (AZL15020001-0850)	X	X	X	
Soldiers Annex Lake (AZL15020008-1430)	X	X	X	
Soldiers Lake (AZL15020008-1440)	X		X	
Long Lake (Lower) (AZL15020008-0820)	X	X	X	
Lake Mary (Upper) (AZL15020015-0900)	X	X	X	
Lake Mary (Lower) (AZL15020015-0890)	X	X	X	
Santa Fe Reservoir (AZL15010004-1340)	X		X	
Roosevelt Lake (AZL15060103-1240)	X	X	X	X
Devils Canyon (AZ15050100-1662)	X	X	X	
Mineral Creek (AZ15050100-012B)	X	X	X	
Tonto Creek (AZ15060105-009)	X	X	X	
Tonto Creek (AZ15060105-004)	X	X	X	
Tonto Creek (AZ15060105-006)	X	X	X	
Tonto Creek (AZ15060105-013B)	X	X	X	
Tonto Creek (AZ15060105-011)	X	X	X	
Tonto Creek (AZ15060105-008)	X	X	X	

Note: Lake Powell (AZL1407006-1130) is not shown because most of the drainage area and Hg sources lie outside Arizona.

6.1 Pollutant Transport Mechanisms

Hg is an environmentally reactive element that is widespread in both abiotic and biotic environments. As it moves through the atmosphere, land, and water, Hg undergoes various chemical and physical transformations. While its presence in the environment is largely driven by human activities, natural sources also contribute. Inorganic Hg occurs in multiple oxidation states. At ambient temperatures, elemental Hg is a dense, mobile liquid metal. It is virtually insoluble in water and has high volatility, leading to exchange from waterbodies to the atmosphere.

In terrestrial and aquatic environments, the majority of Hg exists in an inorganic, oxidized, ionic state. Elemental Hg is virtually insoluble in water; however, ionic Hg in the form of chloride and other salts has significant solubility in water under typical ambient conditions, in equilibrium with a solid-sorbed phase. Under low oxygen conditions inorganic ionic Hg can combine with sulfide to form an insoluble precipitate known as cinnabar (HgS).

Inorganic Hg does not significantly bioaccumulate within food chains; however, under low-oxygen conditions in soil, sediment, and water, microorganisms can methylate inorganic Hg to produce MeHg. MeHg, an organic Hg compound, is partially soluble in water and is the form of Hg that accumulates within aquatic food webs. The majority of MeHg is not loaded to waterbodies but rather is created within waterbodies and adjacent wetland and riparian areas. MeHg is also subject to demethylation, both by bacteria (returning it to an inorganic ionic form) or by photodemethylation by sunlight (which results in conversion to elemental Hg).

The transport of Hg in the waterbody network must address the movement of both dissolved and particle-associated Hg forms and thus depends on both the flow of water and the erosion, transport, and trapping of particulate matter throughout the watershed upstream of each impaired waterbody. The technical approach, including the use of SPARROW, to accomplish this analysis is presented in Section 7.2 and Section A-4.0 of the Technical Support Appendix.

6.2 Point Sources

Various NPDES-permitted point sources are present within Arizona that may affect the water quality of the state's Hg-impaired waterbodies. Table 13 lists and describes the point sources and their locations are illustrated in Figure 9. Permitted facilities identified in Table 13 that are still active will receive WLAs in the TMDL. Data gathering and subsequent estimates of point source Hg load contributions are described in detail in Section A-5.1 of the Technical Support Appendix. Estimates of point source loads of THg are combined with SPARROW-based estimates of delivery through the stream network to estimate the total THg load delivered to each impairment. The resulting delivered mass loading estimates by impaired waterbody are shown in Table 14, and the percentage contributions by source type are summarized in Table 15.

Table 13. Point Sources with NPDES Permits.

Facility/Source	Permit Number ^a	Facility Type	Permit Types	Waterbody ID (WBID)	Waterbody Name
USDOI BR-Glen Canyon Dam and Powerplant	AZ0026182	NON-POTW	Minor	AZL14070006-1130	Lake Powell
Freeport-McMoRan Bagdad, Inc.	AZ0022268 ^b	Mine	Major	AZL15030204-0040A	Alamo Lake
Petro Stopping Center WWTP	AZ0022756	NON-POTW	Minor	AZL15030204-0040A	Alamo Lake
Town of Patagonia WWTP	AZ0025011	POTW	Minor	AZL15050301-1050	Patagonia Lake
Patagonia Lake State Park WWTP	AZ0026620 ^c	POTW	Minor		
January Mine Hermosa Project	AZ0026387 ^b	Mine	Major		
Houston Creek Landing WWTP	AZ0025305 ^b	NON-POTW	Minor	AZ15060105-009 AZL15060103-1240 AZL15060106A-0070 AZL15060106A-0250	Tonto Creek Roosevelt Lake Apache Lake Canyon Lake
City of Globe WWTP	AZ0020249	POTW	Major	AZL15060103-1240 AZL15060106A-0070	Roosevelt Lake Apache Lake
Pinto Valley Mine	AZ0020401	Mine	Major		
Miami Wastewater Reclamation Facility ^d	AZ0025909 ^b	POTW	Minor	AZL15060106A-0250	Canyon Lake
American Gulch WWTP	AZ0020117 ^b	POTW	Major	AZL15060203-0110	Bartlett Lake
Sedona Venture WWTP	AZ0021807	NON-POTW	Minor		
Flagstaff Meadows WWTP	AZ0024708	NON-POTW	Minor		
Pinewood Sanitary District WWTP	AZ0025879	NON-POTW	Minor		
Big Park Domestic Wastewater Improvement District WWTP	AZ0024082	NON-POTW	Minor		
Town of Jerome WWTP	AZ0021804	POTW	Minor		
City of Cottonwood WWTP	AZ0024716	POTW	Major		

Facility/Source	Permit Number ^a	Facility Type	Permit Types	Waterbody ID (WBID)	Waterbody Name
Iron King Water Treatment ^e	AZ0024546 ^b	NON-POTW	Major	AZL15060203-0110	Bartlett Lake
Kings Ranch Unit II WWTP	AZ0023060 ^b	NON-POTW	Minor	AZL15070102-1100	Lake Pleasant
Bensch Ranch Estates WWTP ^f	AZ0024813 ^b	NON-POTW	Minor		
Black Canyon Ranch RV Resort WWTP	AZ0024741	NON-POTW	Minor	AZL15070102-1100	Lake Pleasant
Chimney Estates, LCC WWTP	AZ0026999	NON-POTW	Minor		
Town of Prescott Valley WWTP	AZ0025381	POTW	Major		
Softwinds Mobile Home Park WWTP	AZ0026051	NON-POTW	Minor		

- a. AZPDES permit identification number.
- b. AZPDES facilities without Hg data available in DMR reports (i.e., all entries recorded as “NA”), often due to samples being less than the detection limit used for the analyses.
- c. AZPDES permit AZ0026620 became effective in January 2024. At the time of issuance, no Hg monitoring data was available for the facility, so no Hg limits were initially established. However, ADEQ’s Compliance and Permits Unit calculated an average monthly Hg mass limit of 0.0007 g/day and a maximum daily mass limit of 0.0015 g/day. Since this is a newly permitted discharge, it can be treated as an additional load for future TMDL calculations. This load is not included in the SPARROW-based load analyses for the Patagonia Lake drainage area, which were calibrated using data collected prior to the activation of AZ0026620.
- d. This permit was terminated in 2021.
- e. This permit was terminated in 2013.
- f. This permit was terminated in 2018.
- g. City of Williams WWTP, permit AZ0025755, discharges to the same HUC12 (150100040502) as impaired Santa Fe Reservoir (WBIDAZL15010004-1340); however, the discharge is downstream of the reservoir and is thus excluded from the Hg loading analysis for Santa Fe Reservoir.

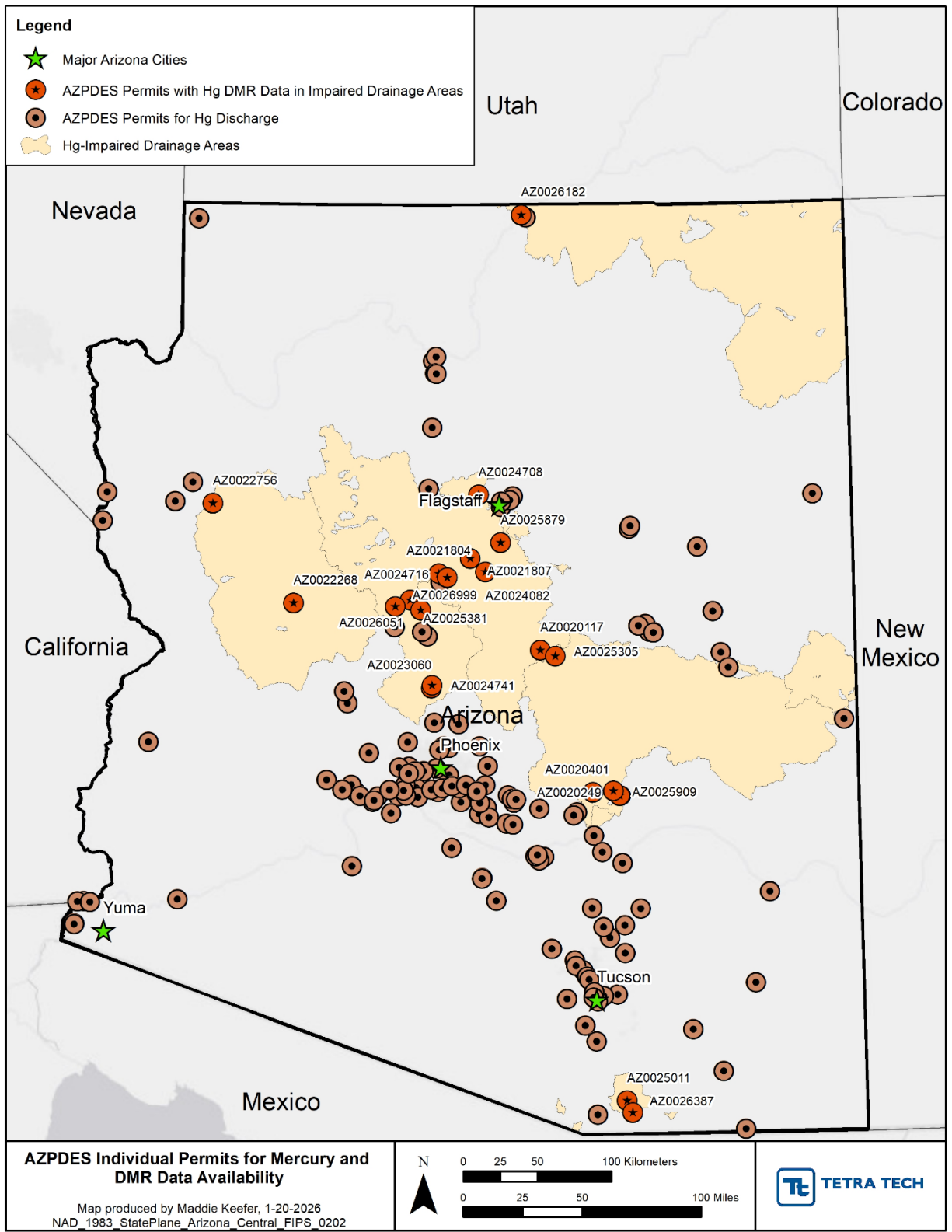


Figure 9. Locations of NPDES Permitted Point Sources.

6.3 Nonpoint Sources

Nonpoint sources of pollution are those which originate from non-permitted areas that reach Arizona's Hg-impaired waterbodies via surface water runoff or groundwater transport. Nonpoint sources may be intermittent in nature and difficult to quantify. Identified nonpoint sources which are known or thought to contribute pollutant loadings to the impaired waterbodies are identified below and described in greater detail in Section A-5.2 of the Technical Support Appendix. Estimates of nonpoint source loads of THg are combined with SPARROW-based estimates of delivery through the stream network to estimate the total THg load delivered to each impairment. The resulting delivered mass loading estimates by impaired waterbody are shown in Table 14, and the percentage contributions by source type are summarized in Table 15.

6.3.1 Atmospheric Deposition

Hg circulates globally in the atmosphere, primarily in elemental and ionic forms. Much of the atmospheric Hg load is derived from coal burning; however, the oceans contain a substantial mass of elemental Hg that equilibrates with the atmosphere so that the atmospheric concentration responds only slowly to reductions in emissions. Deposition of atmospheric Hg is an important and ongoing load source to watersheds and waterbodies worldwide. This atmospheric deposition can occur as wet deposition, associated with precipitation, and dry deposition that occurs in the absence of precipitation. The wet deposition pathway consists primarily of ionic Hg that is dissolved into water droplets in the atmosphere and is relatively easy to measure in rainfall samples. Dry deposition is a more complex and more difficult to measure process that includes bi-directional transport between the atmosphere and land or water surfaces. Dry deposition includes ionic Hg that is associated with fine particulate matter such as smoke or aeolian dust, both of which may also be incorporated into wet deposition; however, a major pathway for dry deposition is the uptake of elemental Hg by plant leaves, much of which is eventually converted into ionic forms and incorporated into soil via leaf litterfall.

The estimation of atmospheric deposition of Hg is described in detail in the Technical Support Appendix (Section A-5.2.1). Gridded summaries of Hg deposition rates were obtained from the Western North American Mercury (WNAM) project (Domagalski *et al.*, 2016). The WNAM project uses monitoring data collected by the National Atmospheric Deposition Program Mercury Deposition Network (NADP-MDN; <http://nadp.sws.uiuc.edu/mdn>) for wet deposition of Hg. Dry deposition of Hg is estimated from the Community Multiscale Air Quality (CMAQ; <https://www.cmascenter.org/cmaq/>) model run for 2009 conditions.

6.3.2 Geological Background Erosion

Hg is present in upland soils, largely in ionic form, due to natural geology combined with decades of atmospheric deposition. Erosion of upland soils can bring this Hg into the stream network. ADEQ estimated these loads by combining SPARROW estimates of upland sediment erosion delivered to the stream network (see Section 7) with estimates of surface soil (top 5 cm) THg concentrations. Hg concentrations in surface soils are based on Smith *et al.* (2019) with separate analyses for areas with and without igneous and hydrothermal geology, which is associated with higher naturally occurring Hg concentrations, as described in Section A-5.2.2 of the Technical Support Appendix.

6.3.3 Stream Sediment and Floodplain Sources (including Mining Sources)

ADEQ assumes that Hg sources associated with historic gold and silver mining operations (e.g., via Hg amalgamation) will tend to be concentrated near streams due to the need for water in ore processing and its use for powering stamp mills to crush ore. Other anthropogenic sources of

Hg, such as abandoned waste sites (e.g., tailings), are also likely to be in low-lying areas across the state. As described in Section 7.2, ADEQ used the SPARROW predictions of sediment generated from stream channels and riparian areas to address near-channel sources of Hg loading. The SPARROW sediment load from channel and riparian erosion is multiplied by a THg potency factor (ng THg/mg TSS) to estimate THg loads from this pathway. Because sediment and Hg loads from near-channel sources are likely to be much larger than the load from upland erosion except during extreme storm events, the sediment potency was assumed to be approximately equal to the average ratio of sediment-sorbed THg to TSS in stream samples. Details are provided in Section A-5.2.3 of the Technical Support Appendix.

6.4 Estimated Existing Delivered Pollutant Loads

Estimates of point source and nonpoint source loads of THg described in Sections A-5.1 and A-5.2 of the Technical Support Appendix are combined with the SPARROW-based estimates of delivery through the stream network to estimate the total THg load delivered to each impaired waterbody segment. The use of SPARROW will be explained in Section 7.2 and Section A-4.0 of the Technical Support Appendix. The resulting delivered mass loading estimates by WBID are shown in Table 14. Note that many of the contributing watersheds associated with an impaired WBID are nested (e.g., Canyon Lake is downstream of Apache Lake which is downstream of Roosevelt Lake), so it is not appropriate to sum columns in Table 14, although the estimate of loading to Canyon Lake does account for losses that occur within the upstream lakes. Percentage contributions by source type are summarized in Table 15. These vary widely by WBID, but for many of the impaired waterbodies, wet atmospheric deposition is a major contributor with a median across all sites of 50 percent.

Table 14. Average Annual Total Hg Loads Delivered to Each Impaired WBID^a.

WBID	Geologic background load (g/yr)	Near-channel load (g/yr)	Wet atmospheric deposition (g/yr)	Dry atmospheric deposition to water (g/yr)	Point source load (g/yr)	Total load (g/yr)
Peña Blanca Lake (AZL15050301-1070)	0.3	<0.1	8.1	1.9	0.0	10.3
Parker Canyon Lake (AZL15050301-1040)	<0.1	<0.1	8.2	5.5	0.0	13.7
Patagonia Lake (AZL15050301-1050)	412.1	262.3	218.3	19.6	22.5	934.7
Arivaca Lake (AZL15050304-0080)	<0.1	<0.1	10.3	4.5	0.0	14.8
Scott Reservoir (AZL15020005-1360)	19.8	16.9	130.7	3.4	0.0	170.8

WBID	Geologic background load (g/yr)	Near-channel load (g/yr)	Wet atmospheric deposition (g/yr)	Dry atmospheric deposition to water (g/yr)	Point source load (g/yr)	Total load (g/yr)
Canyon Lake (AZL15060106A-0250)	3,589.0	5,351.1	18,743.1	900.5	<0.1	28,583.8
Apache Lake (AZL15060106A-0070)	4,574.5	6,353.3	18,643.5	878.9	<0.1	30,450.2
Bartlett Lake (AZL15060203-0110)	3,126.1	5,408.6	10,337.6	356.1	89.8	19,318.2
Lake Pleasant (AZL15070102-1100)	1,081.7	3,137.8	1,656.7	256.5	320.9	6,453.5
Becker Lake ^b (AZL15020001-0150)	9.4	8.8	1.7	0.2	0.0	20.1
Horsethief Lake ^b (AZL15070102-0630)	5.7	0.0	1.0	1.1	0.0	7.8
Willow Springs Lake (AZL15020010-1670)	1.6	0.0	50.5	9.3	0.0	61.4
Black Canyon Lake (AZL15020010-0180)	2.7	0.0	22.4	1.8	0.0	26.9
Alamo Lake (AZL15030204-0040A)	3,397.6	4,537.7	3,297.8	270.7	0.4	11,504.3
Lyman Reservoir (AZL15020001-0850)	4,114.3	1,984.8	909.0	62.4	0.0	7,070.5
Soldiers Annex Lake (AZL15020008-1430)	95.6	14.7	32.3	15.4	0.0	157.9
Soldiers Lake (AZL15020008-1440)	92.0	<0.1	32.3	15.4	0.0	139.7
Long Lake (Lower) (AZL15020008-0820)	98.9	18.0	32.3	15.4	0.0	164.7
Lake Mary (Upper) (AZL15020015-0900)	19.2	35.9	281.9	27.6	0.0	364.6

WBID	Geologic background load (g/yr)	Near-channel load (g/yr)	Wet atmospheric deposition (g/yr)	Dry atmospheric deposition to water (g/yr)	Point source load (g/yr)	Total load (g/yr)
Lake Mary (Lower) (AZL15020015-0890)	89.7	72.7	397.0	52.1	0.0	611.4
Santa Fe Reservoir ^b (AZL15010004-1340)	0.2	0.0	3.9	2.6	0.0	6.8
Roosevelt Lake (AZL15060103-1240)	7,404.8	9,495.9	18,778.8	824.6	<0.1	36,504.1
Devils Canyon (AZ15050100-1662)	2.8	65.0	113.8	4.2	0.0	185.8
Mineral Creek (AZ15050100-012B)	12.1	471.0	259.2	8.7	0.0	751.0
Tonto Creek (AZ15060105-009)	677.4	1,605.8	2,531.3	34.7	0.0	4,849.1
Tonto Creek (AZ15060105-004)	697.2	2,119.1	2,961.1	138.6	0.0	5,916.0
Tonto Creek (AZ15060105-006)	703.2	1,975.6	2,791.6	52.4	0.0	5,522.8
Tonto Creek (AZ15060105-013B)	242.4	609.1	758.5	9.2	0.0	1,619.2
Tonto Creek (AZ15060105-011)	400.9	1,216.7	1,610.6	18.8	0.0	3,246.9
Tonto Creek (AZ15060105-008)	740.2	1,894.0	2,500.3	46.4	0.0	5,181.0

a. Results are calculated at the HUC12 scale.

b. Becker Lake, Horsethief Lake, and Santa Fe Reservoir results are adjusted to account for drainage areas containing fractions of a HUC12.

Table 15. Percentage Contribution of Total Hg Sources Delivered to Each Impaired WBID^a.

WBID	Geologic background load (g/yr)	Near-channel load (g/yr)	Wet atmospheric deposition (g/yr)	Dry atmospheric deposition to water (g/yr)	Point source load (g/yr)
Peña Blanca Lake (AZL15050301-1070)	2.6%	0.1%	78.5%	18.8%	0.0%
Parker Canyon Lake (AZL15050301-1040)	<0.1%	<0.1%	59.9%	40.0%	0.0%
Patagonia Lake (AZL15050301-1050)	44.1%	28.1%	23.4%	2.1%	2.4%
Arivaca Lake (AZL15050304-0080)	<0.1%	<0.1%	69.5%	30.5%	0.0%
Scott Reservoir (AZL15020005-1360)	11.6%	9.9%	76.5%	2.0%	0.0%
Canyon Lake (AZL15060106A-0250)	12.6%	18.7%	65.6%	3.2%	<0.1%
Apache Lake (AZL15060106A-0070)	15.0%	20.9%	61.2%	2.9%	<0.1%
Bartlett Lake (AZL15060203-0110)	16.2%	28.0%	53.5%	1.8%	0.5%
Lake Pleasant (AZL15070102-1100)	16.8%	48.6%	25.7%	4.0%	5.0%
Becker Lake ^b (AZL15020001-0150)	47.0%	43.7%	8.3%	1.0%	0.0%
Horsethief Lake ^b (AZL15070102-0630)	73.2%	0.0%	13.3%	13.5%	0.0%
Willow Springs Lake (AZL15020010-1670)	2.6%	0.0%	82.3%	15.1%	0.0%
Black Canyon Lake (AZL15020010-0180)	10.0%	0.0%	83.2%	6.8%	0.0%
Alamo Lake (AZL15030204-0040A)	29.5%	39.4%	28.7%	2.4%	<0.1%
Lyman Reservoir (AZL15020001-0850)	58.2%	28.1%	12.9%	0.9%	0.0%

WBID	Geologic background load (g/yr)	Near-channel load (g/yr)	Wet atmospheric deposition (g/yr)	Dry atmospheric deposition to water (g/yr)	Point source load (g/yr)
Soldiers Annex Lake (AZL15020008-1430)	60.5%	9.3%	20.4%	9.8%	0.0%
Soldiers Lake (AZL15020008-1440)	65.9%	<0.1%	23.1%	11.1%	0.0%
Long Lake (Lower) (AZL15020008-0820)	60.1%	11.0%	19.6%	9.4%	0.0%
Lake Mary (Upper) (AZL15020015-0900)	5.3%	9.9%	77.3%	7.6%	0.0%
Lake Mary (Lower) (AZL15020015-0890)	14.7%	11.9%	64.9%	8.5%	0.0%
Santa Fe Reservoir ^b (AZL15010004-1340)	3.7%	0.0%	57.7%	38.6%	0.0%
Roosevelt Lake (AZL15060103-1240)	20.3%	26.0%	51.4%	2.3%	<0.1%
Devils Canyon (AZ15050100-1662)	1.5%	35.0%	61.2%	2.3%	0.0%
Mineral Creek (AZ15050100-012B)	1.6%	62.7%	34.5%	1.2%	0.0%
Tonto Creek (AZ15060105-009)	14.0%	33.1%	52.2%	0.7%	0.0%
Tonto Creek (AZ15060105-004)	11.8%	35.8%	50.1%	2.3%	0.0%
Tonto Creek (AZ15060105-006)	12.7%	35.8%	50.5%	0.9%	0.0%
Tonto Creek (AZ15060105-013B)	15.0%	37.6%	46.8%	0.6%	0.0%
Tonto Creek (AZ15060105-011)	12.3%	37.5%	49.6%	0.6%	0.0%
Tonto Creek (AZ15060105-008)	14.3%	36.6%	48.3%	0.9%	0.0%

a. Results are calculated at the HUC12 scale.

- b. *Becker Lake, Horsethief Lake, and Santa Fe Reservoir results are adjusted to account for drainage areas containing fractions of a HUC12.*

Section 7 Technical Approach

7.1 Technical Approaches Considered

In developing the Arizona Statewide Mercury TMDL, multiple technical modeling approaches were considered based on both past Arizona TMDL experiences and insights from other Western state Hg TMDLs. These considerations led to the selection of the USGS Southwest SPARROW model for Hg transport analysis, as discussed in Section 7.2 and the Technical Support Appendix.

Historically, Arizona has used various models in earlier Hg TMDLs for lakes such as Arivaca, Peña Blanca, Alamo (unapproved), and the Lake Mary region (Upper Lake Mary, Lower Lake Mary, Soldiers Lake, Soldiers Annex Lake, and Lower Long Lake). The modeling of Hg in these cases relied on both empirical data and theoretical models to address the complexities of Hg cycling. For instance, the draft Alamo Lake TMDL combined the HEC-5 reservoir simulation with the WASP/TOXI water quality model to account for Hg's behavior in aquatic environments (ADEQ, 2012). Similarly, for the Arivaca and Peña Blanca Lake Hg TMDLs, a conceptual Hg cycling model was developed that linked external Hg loads simulated using the Generalized Watershed Loading Function (GWLF) model (Haith *et al.*, 1992) with in-lake kinetics and bioaccumulation in fish, using the Dynamic Mercury Cycling Model (ADEQ, 1999a; ADEQ, 1999b).

The Lake Mary Regional Hg TMDL employed an integrated approach using four linked models: a watershed loading model, lake hydrologic model, Hg cycling model, and bioaccumulation estimation (ADEQ, 2010). Atmospheric deposition and geological background were identified as primary Hg sources from the technical approach. Site-specific BAFs were applied to predict MeHg in fish tissue under different load scenarios.

Challenges in Hg TMDL development, particularly with modeling Hg's behavior, stem from the weak correlation between external Hg loads and concentrations in biota. Hg's transformation into its more toxic form, MeHg, is largely driven by environmental factors such as dissolved organic carbon, sulfate concentrations, and bacterial activity, making it difficult to directly link Hg sources with fish tissue contamination. This complexity necessitates modeling frameworks that can integrate Hg's transport, transformation, and bioaccumulation based on environmental conditions.

To address these challenges, states have employed diverse modeling approaches. In Oregon's Willamette Basin Hg TMDL, a probabilistic food web model and mass balance model were used to simulate MeHg bioaccumulation, linking it to fish tissue concentrations (USEPA, 2021). A similar BAF approach was utilized in Minnesota's Statewide Mercury TMDL, offering a simplified method of linking ambient MeHg concentrations with fish tissue (Minnesota Pollution Control Agency, 2007).

The Arizona Statewide Mercury TMDL effort evaluated several of these approaches before selecting the USGS SPARROW model for analyzing Hg transport in Arizona's Hg-impaired watersheds. SPARROW is well-suited for regional-scale assessments and incorporates watershed-specific attributes, making it particularly useful for estimating Hg loads across

Arizona's varied hydrological systems. For further information on BAF and SPARROW calculations, refer to Sections A-3.0 and A-4.0 in the Technical Support Appendix.

7.2 Selected Approach

Addressing multiple Hg impairments in a statewide TMDL required an approach that was efficient, relied on existing large-scale models, and could be applied across the state. The general approach has three main components:

1. Determine appropriate TMDL targets. These may be directly specified as ambient water quality criteria for Hg or derived from the relationship between Hg concentrations in water and fish tissue concentration targets, as described in Section 4.
2. Characterize sources of Hg loading, summarized in Section 6.
3. Estimate transport of Hg sources to downstream impaired waterbodies.

The primary tool for analyzing Hg transport in all the impaired watersheds is the USGS SPARROW model. SPARROW model outputs for the Southwestern United States were used as an efficient way to estimate flow and sediment loads for Hg-impaired waterbodies in Arizona (Wise *et al.*, 2019; Miller *et al.*, 2020). SPARROW is an environmental model developed by the USGS to estimate nutrient loads and yields in freshwater systems. The SPARROW model incorporates information on flow and precipitation along with sediment and nutrient transport and is a useful platform for studies such as the Arizona Statewide Mercury TMDL. It also provides a consistent methodology for extrapolation to waterbodies that have limited or no flow and monitoring data. The model is used to assess the sources, transport, and delivery of nutrients from watersheds to streams, rivers, and lakes. Published SPARROW model outputs and results are calibrated and validated using observed flow and nutrient data from local monitoring stations. The associated data release for the Southwest SPARROW model was revised in October 2020 and provides both incremental and accumulated flow and sediment load for each National Hydrography Dataset Plus version 2 (NHDPlusV2) reach and catchment.

SPARROW simulates average annual flow along with sediment and nutrient transport consistent with 2012 land use conditions and point sources. While SPARROW was originally developed for nutrients, it is fundamentally a spatially-referenced regression model that integrates hydrology, sediment transport, and pollutant delivery across watershed attributes. Its application extends beyond nutrients to sediment transport, which is key for Hg analysis. SPARROW's ability to model suspended sediment transport is especially relevant, given Hg's affinity to bind with sediments. See Section A-7.1 and Section A-5.2.3 the Technical Support Appendix for more information on the role of sediment in Hg transport. Flow is estimated using the United States Geological Survey (USGS) Water-Balance Model (WBM), which uses high-resolution gridded meteorological data (Wieczorek *et al.*, 2024). The SPARROW model output provides the total accumulated flow, sediment load, and nutrient load at each stream node as well as the incremental load derived from the local catchment for each segment. SPARROW also predicts accumulated and incremental sediment load derived from channel and near-channel alluvial erosion processes for each stream segment. The channel and near-channel net load estimates enable the calculation of loads derived from riparian areas of specific sets of stream reaches, which is typically where gold and silver mine tailings and ore processing mill waste are found. SPARROW's calculation of incremental sediment input to each NHDPlusV2 reach and total sediment yield at any downstream node also provides a direct estimate of the sediment delivery ratio through the stream network. Sediment loads from the uplands, riparian

areas, and stream bed and banks are combined with information on Hg concentration in sediment to develop the Hg mass balance.

The watershed contributing areas of some of the impaired waterbodies with larger upstream watersheds contain thousands of SPARROW/NHD catchments and reaches. To create a more manageable analysis ADEQ aggregated SPARROW reaches into HUC12 groupings. Each HUC12 grouping was then characterized as to outflow and the sum of upstream and local inflows based on the SPARROW/NHD routing. Within each HUC12 aggregate, Hg sources were tabulated based on whether they are predominantly flow driven (e.g., atmospheric deposition and runoff) or predominantly sediment-associated (including upland erosion and legacy mining sources) as described in Section 6.3. The water-associated loads are then associated with the SPARROW simulation of the water balance and the sediment-associated loads are associated with the SPARROW simulation of sediment transport. Full details of the process are given in the Technical Support Appendix.

Section 8 Linkage Analysis

The purpose of the linkage analysis is to establish the connections or linkages between the loadings to waterbodies (i.e., the causes of impairment) and the water quality response within the receiving waters. This section describes the approach used to characterize waterbody response to pollutant loadings from the watershed.

The SPARROW analysis accounts for the reduction in flow-associated Hg loads associated with water diversions and internally drained subbasins. SPARROW also accounts for the reduction in sediment-associated Hg loads due to trapping in reservoirs and from export of sediment from streams to alluvial and riparian areas. This analysis, however, does not account for other processes that reduce Hg loads, such as the precipitation of insoluble cinnabar and conversion of Hg to the elemental form with subsequent loss to the atmosphere. In general, ADEQ expects the SPARROW-associated loads to be somewhat higher than the actual Hg loads reaching impaired waterbodies. These processes are of particular importance in terminal lakes.

Hg loading rates must be converted to Hg concentrations for comparison to the target total Hg concentrations identified in Section 4 as the more restrictive of ambient water quality criteria for Hg or Hg concentrations sufficient to achieve fish tissue concentration targets based on a BAF analysis. For lakes and reservoirs, concentrations are estimated using steady-state mass balance models, adjusting for hydraulic retention time and sedimentation rates. Concentration (C) is estimated as

$$C = C_i / (1 + \sigma\tau),$$

where C_i is the average flow-weighted input concentration (annual load divided by flow), τ is the hydraulic retention time (V/Q ; yrs), and σ is a net loss/sedimentation rate (per year). For stream segments, concentration is estimated using an equation of the same form; however, the hydraulic retention time is not available from SPARROW, so the product $\sigma\tau$ is replaced by a site-specific generalized loss term that adjusts the SPARROW-predicted concentration to observed data. See Section A-7.1 of the Technical Support Appendix for additional details.

8.1 Spatial Patterns

The Hg transport linkage is based on the detailed hydrologic routing framework of NHDPlusv2. This provides a detailed representation of the spatial patterns of flow, sediment, and pollutant

loading and transport and accounts for the attenuation of load that occurs during the routing process.

8.2 Seasonal Patterns

Low-level Hg concentrations in water are of concern primarily because of the bioaccumulation of MeHg in fish and other biota, which is a long-term, chronic process. The Arizona Hg impairments are assessed based on observed fish tissue concentrations or chronic ambient water quality criteria. In this context, the long-term average exposure concentration is of most concern.

It is expected that there will be seasonal patterns in Hg loading and concentrations that are primarily related to seasonal patterns in precipitation. The SPARROW model does not explicitly provide seasonal results; however, seasonal patterns are implicitly incorporated because flow is derived from the USGS WBM, which is based on monthly time series of precipitation and potential evaporation.

8.3 Calibration to Observed Data

As noted above, actual exposure concentrations in most impaired waterbodies are expected to be somewhat less than the SPARROW-based concentrations due to mass loss processes for Hg that are not represented in SPARROW. To address this issue, the SPARROW simulations are adjusted to agree with observed concentrations by adjusting the loss rate. This allows direct calculation of loading capacity from the concentration equation adjusted for sedimentation and other loss processes.

Total Hg observations with low reporting limits (< 5 ng/L) are available for 18 out of the 30 impaired WBIDs (excluding Lake Powell). The count of observations by impaired waterbody ranges from 1 to 92 and there is considerable uncertainty as to how representative small sample sizes are for long-term average concentrations.

Impaired waterbodies that lack adequate low-level Hg concentration data were generally listed as impaired based on fish tissue data of at least five samples of one species. These fish tissue data can be used to back-calculate an estimate of the local THg exposure concentrations using the BAF (Section 4.3), which is the ratio of fish tissue concentration to exposure concentration.

Hg exposure concentrations based on direct observations and derived from fish tissue concentrations were combined to select a “consensus” exposure concentration. The rationale for selecting consensus THg concentrations for adjusting SPARROW results in individual impaired waterbodies is shown in A-Table 7-1 of the Technical Support Appendix. Preference is given to average observed Hg data when there are data available with a low reporting limit. The median, which is less susceptible to outliers, is used when the data set contains five or less observations or appears to be highly leveraged by an extreme outlier. Where no observed THg data are available estimates based on fish tissue concentration from the species with the most extensive data are used. ADEQ chose the average fish tissue-based estimate for small lakes, where concentrations are more likely to be spatially homogeneous, and the maximum estimate for larger lakes where exposure concentrations are likely to be more variable. Where both fish-based estimates and a limited number of observed THg concentrations are available, a compromise value is selected. Finally, the loss rates were adjusted to bring the SPARROW-based results into approximate agreement with the consensus exposure concentration as shown in A-Table 7-2 of the Technical Support Appendix.

Section 9 TMDL Development

A TMDL is defined as the sum of the WLAs for point sources, plus the sum of the LAs for nonpoint and natural background sources, plus a MOS. This loading budget, with an appropriate MOS, will result in a pattern of loading that the waterbody can process with its available assimilative loading capacity (i.e., TMDL) without exceeding WQS, as shown in the following equation:

$$\text{TMDL} = \sum \text{WLA} + \sum \text{LA} + \text{MOS}$$

where,

$\sum \text{WLA}$ = Sum of all individual point source WLAs

$\sum \text{LA}$ = Sum of all nonpoint source and natural background LAs

MOS = Margin of safety.

The TMDL documented in this section addresses Hg and MeHg impairments listed in the state of Arizona (refer to Table 1). It identifies allowable loadings for point and nonpoint sources discharging to Arizona's Hg-impaired waters.

9.1 Loading Capacity and Allocations

The loading capacity of the waterbody is defined as the quantity of a pollutant or other waterbody constituent which can be absorbed without exceeding applicable WQS.

The loading capacities for Arizona's Hg-impaired waterbodies are calculated using the annual average total recoverable Hg water quality targets of 1.349 ng/L (for lakes and reservoirs), and 1.974 ng/L (for streams) total recoverable Hg (Table 8) where the impairment is based on fish tissue concentrations, or 10 ng/L where the impairment is based on exceeding the chronic ambient water quality criterion. The loading associated with these target concentrations is back-calculated from the final calibrated SPARROW-based models (see Section 7 and the Technical Support Appendix).

The predicted concentration (C^* , after accounting for losses within the impaired waterbody) can be written as

$$C^* = \frac{THg / Outflow}{1 + S} * K$$

where THg is the total Hg loading rate (g/yr), outflow is the flow rate leaving the WBID (cfs); S (unitless) is a factor that adjusts net Hg loss to the loss associated with sedimentation predicted by SPARROW plus other loss or bias correction factors, which are assumed to be a function of the retention time for lake segments; and K is a unit conversion factor to produce C^* in ng/L

units. As S approaches zero the predicted concentration in the impaired waterbody approaches the mass loading divided by the flow.

The variable THg contains all of the point and nonpoint loads of Hg in the watershed upstream of an impaired reach. For nonpoint sources, THg combines the net inputs from atmospheric deposition (to water and to the landscape), upland erosion and runoff, net exchanges with the stream channel bed, banks, and riparian areas, which often store legacy loads of Hg, these estimates were developed from the SPARROW model and other data sources, as is explained in detail in Section A-5.2 of the Technical Support Appendix. The variable S is calibrated to observed concentrations and accounts for transit losses due to enhanced trapping in ponds and depressions, stranding during ephemeral flow, and losses of elemental Hg and MeHg to the atmosphere. Calibration of S is described in Section A-7 of the Technical Support Appendix.

Given a target C* associated with the loading capacity concentration, C_L, THg is equal to the loading capacity (LC) when

$$LC = THg = C_L \times Outflow * (1 + S) * 1/K$$

LC can be converted to a daily load by specifying Outflow on a daily basis. S is generally greater than 1 to account for loss mechanisms beyond what SPARROW simulates as sedimentation. In some cases, S can be less than 1 if there is a significant internal source of Hg loading to the water column within a waterbody. For further discussion on sedimentation and internal sources of Hg loading, see Section A-5.2.3 of the Technical Support Appendix.

The estimated loading capacities are summarized in Table 16.

Table 16. Total Recoverable Hg Loading Capacities for Impaired Waterbodies.

Waterbody ID	Outflow rate (cfs) ^a	Load adjustment fraction	THg target (ng/L)	Calibrated loss factor (S, unitless)	Loading capacity THg (g/yr) ^b
Peña Blanca Lake (AZL15050301-1070)	0.33	1	1.349	4.42	2.15
Parker Canyon Lake (AZL15050301-1040)	0.13	1	1.349	25.09	4.10
Patagonia Lake (AZL15050301-1050)	5.80	1	1.349	94.38	667.14
Arivaca Lake (AZL15050304-0080)	0.20	1	1.349	5.80	1.67
Scott Reservoir (AZL15020005-1360)	5.37	1	1.349	10.26	72.92
Canyon Lake (AZL15060106A-0250)	589.44	1	1.349	31.69	23,228.64
Apache Lake (AZL15060106A-0070)	584.44	1	1.349	16.51	12,335.55

Waterbody ID	Outflow rate (cfs) ^a	Load adjustment fraction	THg target (ng/L)	Calibrated loss factor (S, unitless)	Loading capacity THg (g/yr) ^b
Bartlett Lake (AZL15060203-0110)	328.70	1	1.349	13.78	5,856.23
Lake Pleasant (AZL15070102-1100)	34.74	1	1.349	45.20	1,934.63
Becker Lake (AZL15020001-0150)	0.01	2.61%	1.349	1266.05	643.74
Horsethief Lake (AZL15070102-0630)	0.13	29.41%	1.349	4.91	3.21
Willow Springs Lake (AZL15020010-1670)	2.16	1	1.349	19.23	52.75
Black Canyon Lake (AZL15020010-0180)	1.22	1	1.349	9.11	14.88
Alamo Lake (AZL15030204-0040A)	73.42	1	1.349	50.12	4,524.56
Lyman Reservoir (AZL15020001-0850)	35.36	1	1.349	42.11	1,837.78
Soldiers Annex Lake (AZL15020008-1430)	1.87	1	1.349	4.24	11.80
Soldiers Lake (AZL15020008-1440)	1.94	1	1.349	8.86	23.02
Long Lake (Lower) (AZL15020008-0820)	2.25	1	1.349	4.46	14.84
Lake Mary (Upper) (AZL15020015-0900)	9.89	1	1.349	2.06	36.46
Lake Mary (Lower) (AZL15020015-0890)	15.12	1	1.349	5.52	118.84
Santa Fe Reservoir (AZL15010004-1340)	0.83	64.86%	1.349	-0.92	0.13
Roosevelt Lake (AZL15060103-1240)	585.36	1	1.349	12.07	9,221.73
Devils Canyon (AZ15050100-1662)	2.59	1	10	1.63	60.93
Mineral Creek (AZ15050100-012B)	6.48	1	10	6.63	441.7
Tonto Creek (AZ15060105-009)	58.13	1	1.974	5.62	678.84
Tonto Creek (AZ15060105-004)	69.29	1	1.349 ^b	49.79	4,242.99

Waterbody ID	Outflow rate (cfs) ^a	Load adjustment fraction	THg target (ng/L)	Calibrated loss factor (S, unitless)	Loading capacity THg (g/yr) ^b
Tonto Creek (AZ15060105-006)	68.89	1	1.349 ^c	46.72	3,962.91
Tonto Creek (AZ15060105-013B)	24.37	1	1.974	60.92	2,661.68
Tonto Creek (AZ15060105-011)	47.35	1	1.974	6.67	640.94
Tonto Creek (AZ15060105-008)	63.87	1	1.974	8.08	1,022.65

- a. *Outflow rate is the annual average from SPARROW, load adjustment fraction modifies SPARROW input estimates when the impaired waterbody drains only a portion of a SPARROW catchment or diverts a portion of a SPARROW reach. See Section A-8.0 in the Technical Support Appendix for further details.*
- b. *To express these as average daily load (g/d) to satisfy daily load expression requirements, divide the annual load (g/yr) by 365.*
- c. *For Tonto Creek, WBID AZ15060105-004 is classified as a stream segment but falls within the normal pool footprint of Lake Roosevelt while WBID AZ15060105-004 extends to the edge of Lake Roosevelt. These WBIDs have therefore been assigned the more conservative fish tissue-based water column target calculated for lakes and reservoirs. Neither of these WBIDs would be considered to be impaired relative to the 1.974 ng/L water column target.*

The calculation of the loading capacity for THg in Arizona’s impaired WBID watersheds indicates that large reductions in existing Hg loads are needed to attain the target annual average water column THg concentrations. The reductions calculated to achieve the load capacities calculated from Table 16 are shown in Table 17. The reduction percentages range from zero to 98 percent with a median of 70 percent. The zero percent reduction is estimated in one segment of Tonto Creek (AZ15060105-013B) that lacks evidence of impairment from either water column or fish tissue data obtained within the WBID. Impairment status of this reach may need to be verified with additional sampling.

Table 17. Needed Percent Reductions in Total Hg Loads to Achieve TMDL Targets.

Waterbody ID	Existing THg consensus concentration (ng/L) ^a	Existing THg effective load (g/yr) ^b	Loading capacity THg (g/yr) ^c	5% MOS (g/yr) ^d	Remaining loading capacity (g/yr)	Needed load reduction ^e
Peña Blanca Lake (AZL15050301-1070)	6.50	10.3	2.1	0.1	2.0	80.3%
Parker Canyon Lake (AZL15050301-1040)	4.50	13.7	4.1	0.2	3.9	71.5%
Patagonia Lake (AZL15050301-1050)	1.89	934.7	667.1	33.4	633.8	32.2%

Waterbody ID	Existing THg consensus concentration (ng/L) ^a	Existing THg effective load (g/yr) ^b	Loading capacity THg (g/yr) ^c	5% MOS (g/yr) ^d	Remaining loading capacity (g/yr)	Needed load reduction ^e
Arivaca Lake (AZL15050304-0080)	11.90	14.8	1.7	0.1	1.6	89.2%
Scott Reservoir (AZL15020005-1360)	3.16	170.8	72.9	3.6	69.3	59.4%
Canyon Lake (AZL15060106A-0250)	1.66	28,583.8	23,228.6	1161.4	22,067.2	22.8%
Apache Lake (AZL15060106A-0070)	3.33	30,450.2	12,335.5	616.8	11,718.8	61.5%
Bartlett Lake (AZL15060203-0110)	4.45	19,318.2	5,856.2	292.8	5,563.4	71.2%
Lake Pleasant (AZL15070102-1100)	4.50	6,453.5	1,934.6	96.7	1,837.9	71.5%
Becker Lake (AZL15020001-0150)	1.61	768.3	643.7	32.2	611.6	20.4%
Horsethief Lake (AZL15070102-0630)	3.30	7.8	3.2	0.2	3.0	61.2%
Willow Springs Lake (AZL15020010-1670)	1.57	61.4	52.7	2.6	50.1	18.4%
Black Canyon Lake (AZL15020010-0180)	2.44	26.9	14.9	0.7	14.1	47.5%
Alamo Lake (AZL15030204-0040A)	3.43	11,504.3	4,524.6	226.2	4,298.3	62.6%
Lyman Reservoir (AZL15020001-0850)	5.19	7,070.5	1,837.8	91.9	1,745.9	75.3%
Soldiers Annex Lake (AZL15020008-1430)	18.05	157.9	11.8	0.6	11.2	92.9%
Soldiers Lake (AZL15020008-1440)	8.19	139.7	23.0	1.2	21.9	84.4%
Long Lake (Lower) (AZL15020008-0820)	14.97	164.7	14.8	0.7	14.1	91.4%
Lake Mary (Upper) (AZL15020015-0900)	13.49	364.6	36.5	1.8	34.6	90.5%
Lake Mary (Lower) (AZL15020015-0890)	6.94	611.4	118.8	5.9	112.9	81.5%
Santa Fe Reservoir (AZL15010004-1340)	70.00	6.8	0.1	0.0	0.1	98.2%
Roosevelt Lake (AZL15060103-1240)	5.34	36,504.1	9,221.7	461.1	8,760.6	76.0%

Waterbody ID	Existing THg consensus concentration (ng/L) ^a	Existing THg effective load (g/yr) ^b	Loading capacity THg (g/yr) ^c	5% MOS (g/yr) ^d	Remaining loading capacity (g/yr)	Needed load reduction ^e
Devils Canyon (AZ15050100-1662)	30.50	185.8	60.9	3.0	57.9	68.9%
Mineral Creek (AZ15050100-012B)	17.00	751.0	441.7	22.1	419.6	44.1%
Tonto Creek (AZ15060105-009)	14.10	4,849.1	678.8	33.9	644.9	86.7%
Tonto Creek (AZ15060105-004)	1.88	5,916.0	4,243.0	212.1	4,030.8	31.9%
Tonto Creek (AZ15060105-006)	1.88	5,522.8	3,962.9	198.1	3,764.8	31.8%
Tonto Creek (AZ15060105-013B)	1.20	1,619.2	2,661.7	133.1	2,528.6	0.0%
Tonto Creek (AZ15060105-011)	10.00	3,246.9	640.9	32.0	608.9	81.2%
Tonto Creek (AZ15060105-008)	10.00	5,181.0	1,022.6	51.1	971.5	81.2%

Note: To express these as average daily load (g/d) to satisfy daily load expression requirements, divide the annual load (g/yr) by 365.

- a. Existing THg consensus concentrations are presented and explained in Section A-7.2 of the Technical Support Appendix.
- b. Existing THg effective load is the average annual load rate that yields the consensus concentration based on outflow and calibrated sedimentation/loss rates.
- c. The loading capacity is from Table 16.
- d. A 5% explicit allocation has been reserved from each loading capacity to serve as both the MOS and reserve capacity for future growth. All further loading capacities and percent reduction estimates shown in the document are inclusive of this 5% margin.
- e. The needed reduction is equal to $(\text{THg effective load} - \text{loading capacity} - \text{MOS}) / \text{THg effective load}$.

9.1.1 Wasteload Allocations

The calculated allowable load (TMDL) of Hg that will not cause an exceedance of the applicable water quality standard is the sum of the LAs and WLAs (NPDES sources); therefore, the total allowable load must be apportioned between the nonpoint source loads and wastewater point source loads. For many of the Hg impairments, permitted point source loads contribute well less than 1 percent of the total load and any significant decreases in Hg loading will come from reductions in atmospheric deposition or Hg-enriched sediment sources (i.e., load allocation). Therefore, for most WBIDs, the WLA is set to the existing average load from WWTPs or 1 percent of the loading capacity, whichever is smaller. Assigning one percent to the WLA is equivalent to the cutoff the EPA's Mercury Maps model used to screen watersheds for significant point source impact (USEPA, 2001b). At the WBID scale, WLAs are assigned to point sources affecting individual Hg-impaired WBIDs as follows:

- For WBIDs where the total point source contribution is $\leq 1\%$ of the overall Hg load, the sum of the WLA(s) for all contributing point sources is set to the smaller of (a) the existing average load from the permitted facilities or (b) 1% of the loading capacity. This ensures that existing facilities with very small contributions are not assigned a WLA larger than their current existing load.
- For WBIDs where point sources contribute $>1\%$ of the total load, the needed percent reduction (based on the overall TMDL analysis) is applied to the total existing point source load to calculate the maximum allowable combined WLA for all facilities within the WBID drainage area.

ADEQ is assigning a reserve for future growth to cover new potential sources in a lumped 5% MOS. The resulting WLAs for point sources are summarized by impairment in Table 18, and by individual facility in Table 19. A total sum is assigned for all upstream permits and this sum will need to be divided among permittees. Table 19 provides a WLA matrix that lists each permitted discharger’s average Hg load, the facility-specific WLA, and an indicator of whether a load reduction is required. The matrix explicitly accounts for (1) the three dischargers that discharge to more than one WBID, (2) WBIDs that receive effluent from multiple upstream point sources, and (3) permits for which no representative average Hg loading data were available from the ADEQ facility analysis. For these data-limited permits no WLA is currently assigned; however, the permits must include Hg monitoring with water-quality-based effluent limitations (WQBELs) to protect the receiving waters until ADEQ evaluates reasonable potential and establishes an appropriate WLA. Note that an individual permittee may be upstream of more than one Hg-impaired waterbody and either must meet the most stringent WLA or the WLAs will need to be adjusted to achieve overall reduction targets in each impaired waterbody.

Aligned with an adaptive watershed management approach and as part of the TMDL implementation strategy, ADEQ will continue examining potential localized impacts from point sources in effluent-dominated lakes and streams. Where appropriate, ADEQ may implement additional permit limitations and, if required, establish a site-specific Hg TMDL.

Note: The total WLAs in Table 18 represent the allowable point source delivered to the impaired waterbody after accounting for transit losses (as detailed in Sections A-4.1 and A-5.1 of the Technical Support Appendix). The individual facility WLAs in Table 19 represent the end-of-pipe discharged allocations, which have been proportionally scale to ensure the delivered WLAs in Table 18 are met.

Table 18. Wasteload Allocations for Permitted Point Sources.

Waterbody ID	Existing load (g/yr)	Loading Capacity THg (g/yr)	WLA for point sources (g/yr)	WLA Reduction (%)
Peña Blanca Lake (AZL15050301-1070)	10.3	2.0	0.0	0.0%
Parker Canyon Lake (AZL15050301-1040)	13.7	3.9	0.0	0.0%
Patagonia Lake (AZL15050301-1050)	934.7	633.8	15.2	32.2%
Arivaca Lake (AZL15050304-0080)	14.8	1.6	0.0	0.0%
Scott Reservoir (AZL15020005-1360)	170.8	69.3	0.0	0.0%

Canyon Lake (AZL15060106A-0250)	28,583.8	22,067.2	0.0	0.0%
Apache Lake (AZL15060106A-0070)	30,450.2	11,718.8	0.0	0.0%
Bartlett Lake (AZL15060203-0110)	19,318.2	5,563.4	55.6	38.1%
Lake Pleasant (AZL15070102-1100)	6,453.5	1,837.9	91.4	71.5%
Becker Lake (AZL15020001-0150)	768.3	611.6	0.0	0.0%
Horsethief Lake (AZL15070102-0630)	7.8	3.0	0.0	0.0%
Willow Springs Lake (AZL15020010-1670)	61.4	50.1	0.0	0.0%
Black Canyon Lake (AZL15020010-0180)	26.9	14.1	0.0	0.0%
Alamo Lake (AZL15030204-0040A)	11,504.3	4,298.3	0.4	0.0%
Lyman Reservoir (AZL15020001-0850)	7,070.5	1,745.9	0.0	0.0%
Soldier Annex Lake (AZL15020008-1430)	157.9	11.2	0.0	0.0%
Soldier Lake (AZL15020008-1440)	139.7	21.9	0.0	0.0%
Long Lake (Lower) (AZL15020008-0820)	164.7	14.1	0.0	0.0%
Lake Mary (Upper) (AZL15020015-0900)	364.6	34.6	0.0	0.0%
Lake Mary (Lower) (AZL15020015-0890)	611.4	112.9	0.0	0.0%
Santa Fe Reservoir (AZL15010004-1340)	6.8	0.1	0.0	0.0%
Roosevelt Lake (AZL15060103-1240)	36,504.1	8,760.6	0.0	0.0%
Devils Canyon (AZ15050100-1662)	185.8	57.9	0.0	0.0%
Mineral Creek (AZ15050100-012B)	751.0	419.6	0.0	0.0%
Tonto Creek (AZ15060105-009)	4,849.1	644.9	0.0	0.0%
Tonto Creek (AZ15060105-004)	5,916.0	4,030.8	0.0	0.0%
Tonto Creek (AZ15060105-006)	5,522.8	3,764.8	0.0	0.0%
Tonto Creek (AZ15060105-013B)	1,619.2	2,528.6	0.0	0.0%
Tonto Creek (AZ15060105-011)	3,246.9	608.9	0.0	0.0%
Tonto Creek (AZ15060105-008)	5,181.0	971.5	0.0	0.0%

Note: To express these as average daily load (g/d) to satisfy daily load expression requirements, divide the annual load (g/yr) by 365.

Table 19. WLA Matrix Summary by NPDES Permit Number.

NPDES Permit Number	Facility Name	Facility Type Indicator	Permit Type	Average Hg Load (g/d) ^a	WLA (g/d) ^a	Reduction Needed ^a	Downstream Impairments
AZ0025755	CITY OF WILLIAMS - WWTP	POTW	Non-Major	0.0598	0.0598	No	AZL15010004-1340
AZ0022756	PETRO STOPPING CENTER	NON-POTW	Non-Major	0.0016	0.0016	No	AZL15030204-0040A
AZ0022268	FREEMPORT-MCMORAN BAGDAD INC	NON-POTW	Major	--	--	--	AZL15030204-0040A
AZ0026387	JANUARY ADIT (NORTON MINE)	NON-POTW	Major	--	--	--	AZL15050301-1050
AZ0025011	TOWN OF PATAGONIA - WWTP	POTW	Non-Major	0.0615	0.0417	Yes	AZL15050301-1050
AZ0020401	PINTO VALLEY MINE	NON-POTW	Major	0.0001	0.0001	No	AZL15060103-1240; AZL15060106A-0250; AZL15060106A-0070
AZ0025305	HOUSTON CREEK LANDING - WWTP	NON-POTW	Non-Major	--	--	--	AZ15060105-004; AZ15060105-006; AZ15060105-008; AZ15060105-009; AZL15060103-1240; AZL15060106A-0250; AZL15060106A-0070
AZ0024708	FLAGSTAFF MEADOWS WWTP	NON-POTW	Non-Major	0.1090	0.0675	Yes	AZL15060203-0110

AZ0025879	PINEWOOD COUNTRY CLUB GOLF COURSE AND DRIVING RANGE	NON-POTW	Non-Major	0.0392	0.0243	Yes	AZL15060203-0110
AZ0021807	SEDONA VENTURE	NON-POTW	Non-Major	0.0097	0.0060	Yes	AZL15060203-0110
AZ0024082	BIG PARK DOMESTIC WASTEWATER IMPROVEMENT DISTRICT WWTP	NON-POTW	Non-Major	0.1090	0.0675	Yes	AZL15060203-0110
AZ0021804	JEROME WWTP	POTW	Non-Major	0.0285	0.0176	Yes	AZL15060203-0110
AZ0024716	COTTONWOOD WWTP	POTW	Major	0.2498	0.1547	Yes	AZL15060203-0110
AZ0020117	AMERICAN GULCH WASTEWATER TREATMENT PLANT	POTW	Major	--	--	--	AZL15060203-0110
AZ0025381	TOWN OF PRESCOTT VALLEY - WWTP	POTW	Major	0.9551	0.2720	Yes	AZL15070102-1100
AZ0026051	SOFTWINDS MOBILE HOME PARK WASTEWATER TREATMENT PLANT	NON-POTW	Non-Major	0.0021	0.0006	Yes	AZL15070102-1100

AZ0026999	GAMBEL QUAIL MOBILE HOME AND RV PARK	NON-POTW	Non-Major	0.0020	0.0006	Yes	AZL15070102-1100
AZ0025925	CHIMNEY RANCH MHP	NON-POTW	Non-Major	0.2051	0.0584	Yes	AZL15070102-1100
AZ0024741	BLACK CANYON RANCH RV RESORT WWTP	NON-POTW	Non-Major	0.0048	0.0014	Yes	AZL15070102-1100
AZ0023060	KINGS RANCH - UNIT II WWTP	NON-POTW	Non-Major	--	--	--	AZL15070102-1100

a. “—” indicates no average Hg loading data available for the discharger; thus, while no WLA is established, these permits must include monitoring with WQBELs for Hg to protect receiving waters.

9.1.2 Load Allocations

LAs represent the assignment of a portion of the TMDL to nonpoint sources. These allocations must be made even when there is uncertainty about the magnitude of the existing loads. As this TMDL explicitly reserves 5% of the overall loading capacity to serve as a combined MOS and reserve for future growth, the sum of the LAs is equal to the remaining loading capacity minus the WLAs. LAs shown in Table 20 are based on achieving an equal percent reduction in each nonpoint source category. As with the WLAs, several of the impaired watersheds are nested within other impaired watersheds and the final implementation plan will need to assure that loading capacity is achieved in each of the impairments.

Table 20. Load Allocations for Hg Impaired Segments.

Waterbody ID	Existing Load to Impairment (g/yr)	Loading Capacity THg (g/yr)	WLA to All Point Sources (g/yr)	LAs to All Nonpoint Sources (g/yr) ^a	LA to Natural Background (g/yr)	LA to Legacy Mining Sources (g/yr)	LA to Atmospheric Deposition (g/yr)
Peña Blanca Lake (AZL15050301-1070)	10.3	2.0	0.0	2.0	0.1	0.0	2.0
Parker Canyon Lake (AZL15050301-1040)	13.7	3.9	0.0	3.9	0.0	0.0	3.9
Patagonia Lake (AZL15050301-1050)	934.7	633.8	15.2	618.6	279.5	177.8	161.3
Arivaca Lake (AZL15050304-0080)	14.8	1.6	0.0	1.6	0.0	0.0	1.6
Scott Reservoir (AZL15020005-1360)	170.8	69.3	0.0	69.3	8.0	6.8	54.4
Canyon Lake (AZL15060106A-0250)	28,583.8	22,067.2	0.0	22,067.2	2,770.8	4,131.2	15,165.3
Apache Lake (AZL15060106A-0070)	30,450.2	11,718.8	0.0	11,718.8	1,760.5	2,445.1	7,513.2
Bartlett Lake (AZL15060203-0110)	19,318.2	5,563.4	55.6	5,507.8	895.4	1,549.2	3,063.1
Lake Pleasant (AZL15070102-1100)	6,453.5	1,837.9	91.4	1,746.5	308.1	893.6	544.9
Becker Lake (AZL15020001-0150)	768.3	611.6	0.0	611.6	287.3	267.2	57.1
Horsethief Lake (AZL15070102-0630)	7.8	3.0	0.0	3.0	2.2	0.0	0.8
Willow Springs Lake (AZL15020010-1670)	61.4	50.1	0.0	50.1	1.3	0.0	48.8
Black Canyon Lake (AZL15020010-0180)	26.9	14.1	0.0	14.1	1.4	0.0	12.7
Alamo Lake (AZL15030204-0040A)	11,504.3	4,298.3	0.4	4,297.9	1,269.4	1,695.3	1,333.2
Lyman Reservoir (AZL15020001-0850)	7,070.5	1,745.9	0.0	1,745.9	1,015.9	490.1	239.9
Soldier Annex Lake (AZL15020008-1430)	157.9	11.2	0.0	11.2	6.8	1.0	3.4

Waterbody ID	Existing Load to Impairment (g/yr)	Loading Capacity THg (g/yr)	WLA to All Point Sources (g/yr)	LAs to All Nonpoint Sources (g/yr) ^a	LA to Natural Background (g/yr)	LA to Legacy Mining Sources (g/yr)	LA to Atmospheric Deposition (g/yr)
Soldier Lake (AZL15020008-1440)	139.7	21.9	0.0	21.9	14.4	0.0	7.5
Long Lake (Lower) (AZL15020008-0820)	164.7	14.1	0.0	14.1	8.5	1.5	4.1
Lake Mary (Upper) (AZL15020015-0900)	364.6	34.6	0.0	34.6	1.8	3.4	29.4
Lake Mary (Lower) (AZL15020015-0890)	611.4	112.9	0.0	112.9	16.6	13.4	82.9
Santa Fe Reservoir (AZL15010004-1340)	6.8	0.1	0.0	0.1	0.0	0.0	0.1
Roosevelt Lake (AZL15060103-1240)	36,504.1	8,760.6	0.0	8,760.6	1,777.1	2,278.9	4,704.6
Devils Canyon (AZ15050100-1662)	185.8	57.9	0.0	57.9	0.9	20.2	36.8
Mineral Creek (AZ15050100-012B)	751.0	419.6	0.0	419.6	6.8	263.1	149.7
Tonto Creek (AZ15060105-009)	4,849.1	644.9	0.0	644.9	90.1	213.6	341.2
Tonto Creek (AZ15060105-004)	5,916.0	4,030.8	0.0	4,030.8	475.0	1,443.8	2,112.0
Tonto Creek (AZ15060105-006)	5,522.8	3,764.8	0.0	3,764.8	479.3	1,346.7	1,938.7
Tonto Creek (AZ15060105-013B)	1,619.2	2,528.6	0.0	2,528.6	378.6	951.1	1,198.9
Tonto Creek (AZ15060105-011)	3,246.9	608.9	0.0	608.9	75.2	228.2	305.6
Tonto Creek (AZ15060105-008)	5,181.0	971.5	0.0	971.5	138.8	355.2	477.5

Note: To express these as average daily load (g/d) to satisfy daily load expression requirements, divide the annual load (g/yr) by 365.

a. The last three columns of the table (LA to Natural Background (g/yr), LA to Legacy Mining Sources (g/yr), and LA to Atmospheric Deposition (g/yr)) are a subset of the "LAs to All Nonpoint Sources" column.

9.2 Seasonality and Critical Conditions

Seasonal variations and "... critical conditions for stream flow, loading, and water quality parameters" as outlined in 40 C.F.R. § 130.7(c)(1) are considered in this TMDL. Fish accumulate MeHg over their lifespan to levels that pose health risks to humans and wildlife, with Hg levels in water fluctuating according to seasonal rainfall. However, because this TMDL uses an average annual load, seasonal variations are not a primary concern; MeHg concentrations in fish tissues reflect cumulative temporal variation up to the time of sampling. Variability among individual fish due to factors like size, diet, habitat, and other influences is likely more substantial than seasonal variability.

Traditional critical conditions, such as 7Q10 flow and minimum daily dissolved oxygen analyses, do not directly apply to Hg in fish or chronic water quality criteria, as fish tissue MeHg levels represent long-term accumulation. However, critical conditions are relevant for waterbodies more sensitive to Hg loading due to their water chemistry. This aspect of critical conditions has been accounted for in this TMDL by incorporating site-specific adjustments to sedimentation rates, aligning SPARROW-based load estimates with observed concentrations.

9.3 Margin of Safety

MOS is included in the TMDL to account for uncertainty regarding the relationship between pollutant loads and the water quality response of receiving waterbodies. MOS may be formulated implicitly, using conservative assumptions or analytical techniques, or explicitly by reserving a portion of the loading capacity as an unallocated load.

In this Hg TMDL, uncertainty arises from the Hg movement through the environment, and, in particular, the conversion of inorganic Hg to MeHg. Very important, but still not completely understood, are the structure of the bacterial communities that methylate Hg. Hg methylation was long believed to be due to the activities of sulfate-reducing bacteria; however, recent research suggests that the methylation is carried out by other bacterial groups that thrive in the presence of sulfate reducers, but only up to a point at which excess sulfide production inhibits the methylating bacteria (Peterson *et al.*, 2023). Hg methylation rates are thus most likely to be elevated when there is sufficient, but not too much sulfate present.

Atmospheric sulfate sources are currently being reduced through various initiatives at both federal and state levels, which could lead to meaningful decreases in fish MeHg levels. The connection between sulfate concentrations and MeHg levels – and, consequently, MeHg bioaccumulation in fish – is well supported, though not to the extent that an explicit MOS can be defined. These expected future reductions in sulfate deposition are incorporated as an implicit MOS.

Other conservative assumptions contributing to the implicit MOS are:

- The goals for reduction in atmospheric deposition must be set to achieve the most stringent percent reduction among the impaired waterbodies. Because atmospheric deposition has a strong component of national and global inputs attaining the needed reduction for the most stringent case will result in extra reductions for other impaired waterbodies that will form a significant, although not quantified, MOS. These goals are likely to be achieved given the national and international programs for Hg reductions (EPA 2025). Legacy mining activities, especially the use of Hg amalgamation for gold and silver ore processing, historically appeared to have contributed a significant fraction of current Hg loads to Arizona's Hg-impaired waterbodies. Large-scale gold and silver mining is no longer commercially conducted in Arizona although some small-scale and "hobby" mining does continue. The use of Hg amalgamation in

these mining activities has been greatly reduced by restrictions on the availability of bulk Hg and regulations regarding its disposal should decrease Hg loading to these waters in the future.

- Reduction needs are estimated for each impaired waterbody individually. Many of the impaired waterbody watersheds are nested, such that one is upstream of another. Current allocations do not account for reductions being achieved in upstream waterbodies, adding another layer of conservatism.

Together, these conservative assumptions are believed to result in a large, although unquantified, implicit MOS. In addition to the implicit MOS, this TMDL also includes a 5% explicit MOS, which is reserved from the overall loading capacity. This explicit MOS is lumped to cover both a margin of safety and reserve capacity for future growth. Table 17 presents loading capacities that incorporate this 5% explicit MOS, and all subsequent tables presenting loading capacities by WBID are inclusive of this explicit MOS allocation.

Section 10 Implementation Planning

The allocations (WLAs and LAs) described in this TMDL report are designed to return the targeted impaired waterbodies to attainment with their designated uses under Arizona's WQS. Per A.R.S. § 49-234(G) and (H), TMDLs must include an implementation plan that outlines the methods of achieving the stated load reductions and provides a time frame in which compliance with WQS is expected to be achieved. Because this statewide Hg impairment involves significant loading from natural sources (atmospheric deposition), and from activities that have already ceased (legacy mining), this plan utilizes the statute's allowance for a longer time frame and a phased process. The required time frame is established chronologically through the Phased Restoration Framework (Section 10.2.3) and the recurring 5-Year Assessment and Monitoring cycle (Section 10.4). Furthermore, per A.R.S. § 49-234(G), any reductions in loadings from nonpoint sources shall be achieved voluntarily. This section identifies implementation actions that will further efforts to attain the requirements of the TMDL and associated allocations.

10.1 Point Sources

Various AZPDES-permitted point sources are present within Arizona that may affect the water quality of the state's Hg-impaired waterbodies. However, for the vast majority of these impairments, permitted point sources contribute well under 1% of the total Hg load, with nonpoint sources acting as the dominant drivers of the impairment.

Because nonpoint sources dominate the statewide Hg budget, ADEQ prioritizes facilities where the point source contribution is greater than 1% of the total load at the HUC12 subwatershed scale (Table 21). This 1% threshold is based on the cutoff established by the EPA's Mercury Maps model used to screen watersheds for significant point source impacts (EPA, 2001b). In the Verde River Basin, while point source contributions to Bartlett Lake (specifically Sedona Venture, City of Cottonwood, and Flagstaff Meadows WWTPs) appear low in Table 15, they are prioritized due to their cumulative load and their location upstream of Bartlett Lake. Additionally, the Freeport-McMoRan Facility is included due to its potential for high-volume 'pulse-loading' during extreme storm events. Because Hg accumulates in terminal lake sediments, managing these infrequent but high-magnitude dischargers is important.

ADEQ will incorporate effluent limitations that are consistent with the assumptions and requirements of the WLAs assigned to each permittee during their respective permit renewals, per the provisions of A.A.C. R18-9-B906 and R18-9-A905.

Table 21. AZPDES Permittees and Permit Renewal Cycles.

Permittee Name	Facility Design Flow Rate (MGD)	AZPDES ID/Permit Type	Current Permit Effective Date	Next Permit Renewal ^a
Sedona Venture WWTP	0.10	AZ0021807	5/8/2026	11/8/2030
Town of Patagonia WWTP	0.11	AZ0025011	7/9/2025	1/9/2030
City of Cottonwood WWTP	1.5	AZ0024716	4/14/2022	10/15/2026
Freeport-McMoRan Bagdad Inc	N/A	AZ0022268	8/4/2025	2/4/2030
Flagstaff Meadows WWTP	0.165	AZ0024708	5/27/2022	11/27/2026
Town of Prescott Valley WWTP	3.75	AZ0025381	2/23/2022	8/26/2026

a. Pursuant to A.A.C R18-9-B904, permittees must reapply 180 days before the current permit expires.

Each facility listed maintains AZPDES permit coverage and monitors their effluent for Hg; see Table 22 for monitoring locations and frequency.

Table 22. Point Source Monitoring Plan.

Permittee Name	Receiving Waterbody	Ultimate Hg-Impaired Waterbody	Monitoring Site	Latitude and Longitude	Frequency
Sedona Venture WWTP	Dry Creek (Verde River Basin)	Bartlett Lake	Outfall 001	34.845333, -111.873722	1x/6 months
Town of Patagonia WWTP	Sonoita Creek (Santa Cruz River Basin)	Patagonia Lake	Outfall 001	31.537500, -110.758333	1x/6 months
City of Cottonwood WWTP	Del Monte Wash (Verde River Basin)	Bartlett Lake	Outfall 001	34.732500, -112.042222	1x/6 months
Freeport-McMoRan Bagdad Inc.	Tributaries to Boulder Creek and Burrow Creek (Bill Williams River Basin)	Alamo Lake	Outfall 003/ Outfall 006	003: 34.597778, -113.256389 006: 34.588056, -113.289444	1x/discharge

Permittee Name	Receiving Waterbody	Ultimate Hg-Impaired Waterbody	Monitoring Site	Latitude and Longitude	Frequency
Flagstaff Meadows WWTP	Unnamed Wash (Verde River Basin)	Bartlett Lake	Outfall 001	35.231539, -111.811200	1x/6 months
Town of Prescott Valley WWTP	Unnamed Wash (Agua Fria River Basin)	Lake Pleasant	Outfall 001	34.587222, -112.271667	1x/quarter

While Tables 21 and 22 identify point sources due to their localized contributions, it is important to contextualize that even these facilities remain minor in the grand scheme of the statewide Hg budget. Because their physical load contributions are so small, these permittees are not required to implement large-scale infrastructure upgrades. The Reasonable Potential (RP) — or the likelihood that a facility will exceed WQS — currently listed as indeterminate for three of these facilities (City of Cottonwood WWTP, Flagstaff Meadows WWTP, and Town of Prescott Valley WWTP) because previous lab results used Limits of Quantitation (LOQs) that were too high; the testing was not sensitive enough to detect low-level concentrations. Therefore, a transition to a more sensitive analytical method (such as EPA Method 245.7 or 1631E) to achieve a reporting limit at or below the 0.01 µg/L WQS is essential to move the facilities beyond indeterminate status and verify that loading levels are within the assigned WLAs. While current monitoring frequencies must be maintained, if treated effluent is diverted for reuse rather than discharged directly to receiving waters, exceptions to monitoring sensitivity requirements may be considered. Freeport-McMoRan Bagdad Inc. has an indeterminate RP due to absence of data. RP exists for Sedona Venture WWTP and there is no RP for Town of Patagonia WWTP.

10.2 Nonpoint Sources

Per A.R.S. § 49-234(G), "Any reductions in loadings from nonpoint sources shall be achieved voluntarily." The proposed actions in this section are provided for internal management and public planning purposes. This plan should not be construed as a rule or regulation.

In alignment with regional and national precedents for Hg management, the dominance of nonpoint source contributions in Arizona—specifically atmospheric deposition and legacy sediment mobilization—reflects the findings of other EPA-approved statewide Hg TMDLs. These large-scale assessments consistently demonstrate that the vast majority of Hg loading in impaired watersheds originates from global atmospheric flux and historical land-use impacts rather than active industrial or municipal point sources. By focusing implementation on national emission advocacy, localized sediment stabilization, and identification of high priority Hg-contributing sites such as historic mines and lake sediments, ADEQ adheres to a proven regulatory path that acknowledges the transboundary nature of Hg while prioritizing reasonable assurance through the management of legacy Hg deposits.

10.2.1 Historical Considerations and Completed Actions

Efforts to mitigate Hg loading and manage public health risks have been ongoing in Arizona for decades (Table 23). These actions have primarily focused on identifying legacy mining sites associated with Hg contamination and reducing the potential for human exposure through contaminated fish.

Table 23. Completed Hg Mitigation and Management Activities.

Responsible Parties	Action	Result	Year Completed
ADEQ	Seven waterbody-specific Hg TMDLs (Arivaca Lake, Pena Blanca Lake, and the Lake Mary Regional Lakes).	Established initial load reduction targets for Hg-impaired lakes.	1999–2010
ADEQ, Arizona Game & Fish Dept (AZGFD)	Statewide Fish Tissue Monitoring Program.	Compiled 1,458 samples over 30 years to identify Hg-impaired waterbodies.	1995–2022
EPA	Clean Air Act Mercury and Air Toxics Standards (MATS).	Significant reduction in Hg and toxic air emissions from coal- and oil-fired power plants nationally.	2012–2020
AZ Power Utilities	Conversion of Apache Generating Station Unit ST2 (Steam Turbine 2) from coal to natural gas.	Reduced local atmospheric Hg contributions within Arizona watersheds.	2017
ADEQ, USFS, EPA	Remediation and stabilization of historical abandoned mine lands (AMLs) and tailings within Hg-impaired watersheds. (For a comprehensive list of completed projects, refer to the EPA GRTS database).	Reduced localized nonpoint source legacy Hg and sediment loading to surface waters.	Various

10.2.2 Ongoing Actions

ADEQ and its partners continue to sustain restoration efforts through active monitoring and regional collaboration to address the global and local nature of Hg pollution (Table 24).

Table 24. Ongoing Activities.

Responsible Parties	Action	Intended Result
ADEQ, AZGFD	Annual AZGFD Outdoor Expo.	Maintain public awareness of MeHg bioaccumulation risks and Fish Consumption Advisories.
ADEQ	TMDL 5 Year Reviews.	Evaluation of attainment status and decision to either maintain or modify existing TMDLs and implementation plans.
ADEQ, AZGFD	Ongoing Fish Tissue Monitoring and Public Outreach.	Track progress toward 0.3 mg/kg MeHg fish tissue target and ensure public is informed on safe fish consumption.
Arizona Electric Power Cooperative (AEP CO)	Ceasing coal operations at Apache Generating Station Unit ST3 (Steam Turbine 3) by 2027.	Significant reduction in long-term regional atmospheric Hg emissions and deposition.
Salt River Project (SRP)	Conversion of Coronado Generating Station to natural gas by 2029.	Significant reduction in long-term regional atmospheric Hg emissions and deposition.
Tucson Electric Power (TEP), SRP	Conversion of Springerville Units 1 and 2 to natural gas by 2030.	Significant reduction in long-term regional atmospheric Hg emissions and deposition.
ADEQ, USFS, EPA, Landowners	Ongoing assessment and remediation of AML sites to prevent legacy Hg transport. (Refer to the EPA GRTS database for active projects).	Continued reduction of localized nonpoint source legacy Hg and sediment loading to surface waters.
ADEQ	Active membership in National Association of Clean Air Agencies (NACAA).	Engagement on Hg issues at that national issue through NACAA.

10.2.3 Future Actions and Monitoring

To ensure the most effective allocation of resources, ADEQ will implement a Phased Restoration Framework that progresses from broad-scale waterbody prioritization to site-specific BMPs, complemented by ongoing strategic advocacy. This process is conceptualized as a strategic workflow “funnel” (Figure 10), which filters state-wide impairment data into targeted, high-impact management actions.

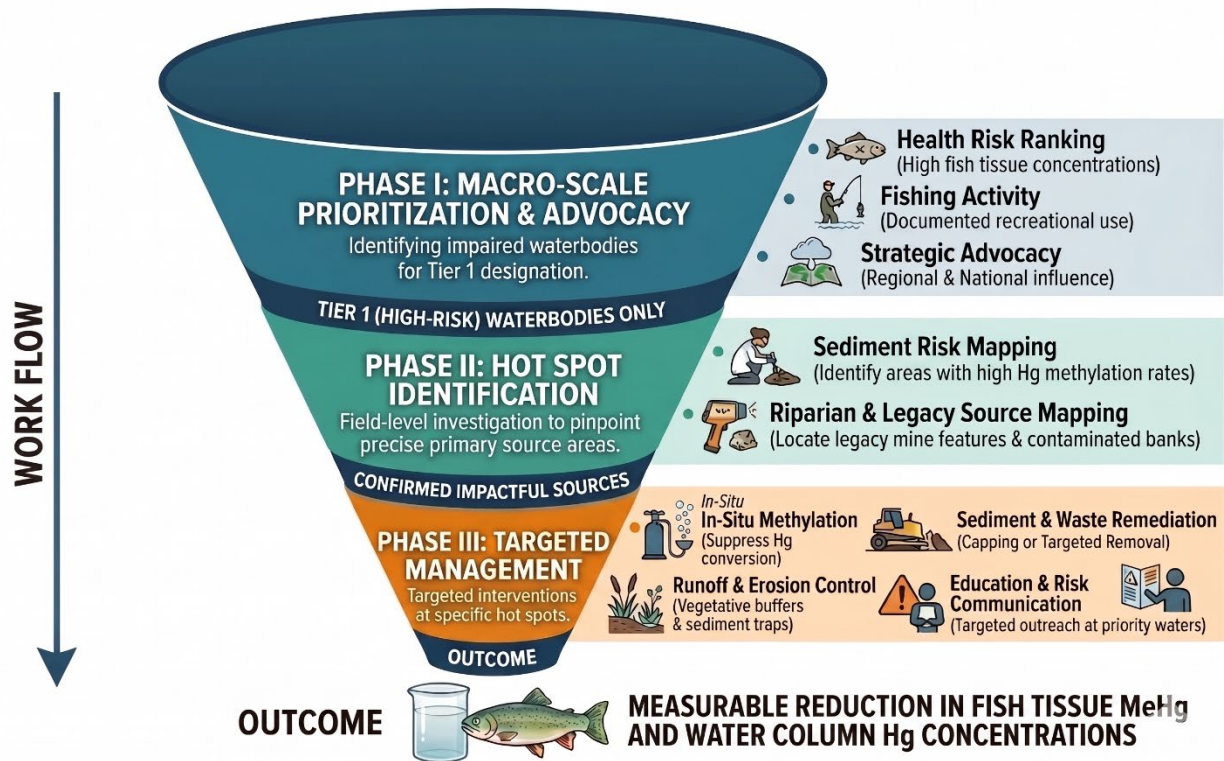


Figure 10. Phased Restoration Framework - Work Flow Funnel.

This process consists of three distinct phases:

- I. **Macro-Scale Prioritization & Strategic Advocacy:** ADEQ intends to prioritize the 31 impaired segments based on documented human health risk and recreational usage. Concurrently, the Department plans to engage in National and Regional Advocacy to address the transboundary nature of Hg. This includes seeking to collaborate with EPA and regional western states, tribal lands and international partners to support emission reduction standards, acknowledging that atmospheric deposition is a primary driver of Hg loading in Arizona.
- II. **Diagnostic 'Hot Spot' Identification:** Once prioritized, waterbodies may undergo high-resolution field screening—including sediment profiling in reservoirs and handheld XRF mapping in stream floodplains and adjacent AMLs—to pinpoint where legacy Hg is entering the system.
- III. **Targeted Management Implementation:** Based on Phase II results, the Department will evaluate the feasibility of collaborating with appropriate lead parties to encourage the deployment of engineering controls and sediment BMPs, such as in-situ methylation suppression in reservoirs or physical stabilization of target legacy mine tailings.

This phased approach ensures ADEQ is actively reducing local Hg load sources while simultaneously advocating for the broad-scale atmospheric reductions necessary for long-term WQS attainment.

Tables 25–27 outline the specific, actionable components of the Phased Restoration Framework. Each action is assigned a unique identifier to facilitate long-term tracking and includes the target for success and potential responsible parties. This structured format ensures that the progression from broad-scale waterbody prioritization to site-specific BMPS implementation is transparent, auditable, and scientifically defensible.

PHASE I: MACRO-SCALE PRIORITIZATION AND STRATEGIC ADVOCACY

The restoration process begins by ranking Arizona’s impaired waterbodies into tiers based on available data, focusing on where Hg concentrations and fishing activity are the highest. The actions in Table 25 utilize current fish tissue results and recreational usage data to ensure the most significant health risks are addressed first. Table 25 also includes tangible advocacy actions aimed at reducing the regional and national air emissions that contribute to Arizona’s current Hg levels. The prioritization occurring in this initial phase ensures that subsequent field work is directed toward the waterbodies where it will be the most beneficial for the health and well-being of wildlife and the public.

To address data uncertainty within this phased approach, ADEQ will prioritize confirmational sampling for segments requiring a 0% load reduction or lacking impairment evidence, such as Tonto Creek (AZ15060105-013B). These sampling results will be used to either support a formal delisting process or recalculate necessary TMDL allocations.

Table 25. Phase I Activities.

Action ID	Implementation Activity	Target/Goal	Potential Lead Party
A-1.1	Health Risk Ranking	A ranked list of Hg-impaired waterbodies that is informed by fish tissue concentrations and fishing activity.	ADEQ TMDL Team
A-1.2	Regional Advocacy	Participation in Western States Air Resources Council (WESTAR) and EPA Region 9 technical workgroups to represent Arizona’s interests.	ADEQ Air Quality Division & TMDL Team
A-1.3	Official Regulatory Input	Writing and submitting ADEQ’s formal technical opinions on proposed federal air quality rules.	ADEQ Air Quality Division & TMDL Team
A-1.4	Transboundary Data Sharing	Collaboration with neighboring states to unify Hg reduction efforts and strengthening our collective regional influence on federal policy.	ADEQ Air Quality Division & TMDL Team
A-1.5	Continued membership in NACAA	Engagement on Hg issues at national level.	ADEQ

Action ID	Implementation Activity	Target/Goal	Potential Lead Party
A-1.6	Confirmational Sampling and Impairment Verification	Collect current water column and/or fish data for segments with data uncertainty (e.g. Tonto Creek AZ15060105-013B) to support formal delisting or future TMDL allocation recalculation.	ADEQ

PHASE II: HOT SPOT IDENTIFICATION

Following the prioritization of Hg-impaired waterbodies, the implementation process transitions to Phase II: Hot Spot Identification for the highest-ranked waterbodies identified in Phase I. The actions in Table 26 utilize targeted, field-level investigations to pinpoint the primary source areas within these priority watersheds. High-resolution tools – such as sediment profiling and X-ray Fluorescence (XRF) mapping - provide the data necessary to identify key Hg sources in legacy mine features or lake sediments.

Table 26. Phase II Activities.

Action ID	Implementation Activity	Target/Goal	Potential Lead Party
B-2.1	Lake Sediment Sampling	Sampling lake sediments in Phase I priority reservoirs to identify areas where Hg methylation rates are highest.	ADEQ, Lake Managers, AZ Game and Fish
B-2.2	Soil and XRF Mapping	Targeted screening of legacy mine wastes within Phase I priority watersheds to identify Hg hot spots.	ADEQ

PHASE III: TARGETED MANAGEMENT ACTIONS

Once primary sources are identified and mapped, the process moves to Phase III: Targeted Management Actions. Rather than applying broad, watershed-wide BMPs, the actions in Table 27 focus on interventions at specific hot spots identified in Phase II. Concentrating resources on these high-impact areas maximizes the potential for measurable reductions of MeHg in fish tissue and provides the most efficient path towards water quality attainment.

Table 27. Phase III Activities.

Action ID	Implementation Activity	Target/Goal	Potential Lead Party
C-3.1	Selective Dredging or Capping	Targeted removal or covering of the top layer of lakebed sediments to reduce Hg methylation formation rates.	Lake Managers, counties/municipalities, state parks
C-3.2	Sediment & Waste Remediation	Encapsulating or removing legacy mine wastes and contaminated soils to prevent Hg transport.	USFS, ADEQ, Landowners
C-3.3	Runoff and Erosion Control	Stabilizing slopes and drainage pathways to intercept Hg-laden sediment before it reaches waterbodies.	USFS, ADEQ, Landowners
C-3.4	Public Education & Risk Communication	Coordinate with health agencies for fish consumption outreach, signage, and public education at priority waterbodies.	ADEQ Communications and Community Science Alliance
C-3.5	Methylation control via deep-water aeration	Decreasing Hg methylation formation rates in lake bottoms.	Lake Managers, Counties/Municipalities, State Parks
C-3.6	Intensive Fishery Management and Biomass Removal	Reducing biotic MeHg burdens through targeted predatory fish removal, population reduction, or total fish eradication and restocking.	AZGFD, Lake Managers

While the ultimate goal of Phase III is the attainment of fish tissue standards, ADEQ recognizes that Hg cycling involves significant biological lag times. Within this framework, any statistically significant downward trend in Hg concentrations – whether in sediment, water column, or fish tissue, is considered a primary success. Incremental improvements represent a direct reduction in community health risk and validate the effectiveness of the targeted management actions.

10.3 Stakeholder Collaboration

ADEQ relies on a broad network of partners to champion restoration efforts. While high-level coordination with federal and state agencies remains essential, successful TMDL implementation also requires the active participation of local organizations, as these groups possess critical knowledge about local priorities and economics. ADEQ aims to foster a strong sense of community ownership over the voluntary nonpoint source reductions necessary to achieve WQS.

To turn these partnerships into real on-the-ground results, ADEQ supports creating local stakeholder workgroups. These groups will help figure out the most practical ways to reduce pollution, plan specific projects, and share data to track progress. Stakeholders will also play a major role in finding and applying for funding.

These partnerships are essential for carrying out the Phased Restoration Framework. Local projects, such as managing sediment and controlling erosion, will require close teamwork with counties, cities, and private landowners. ADEQ will also continue to collaborate with state and local health and wildlife agencies to educate the public about safe fish consumption. Finally, as power companies continue switching their regional power plants from coal to natural gas, these industry partners are helping to guarantee that airborne Hg pollution will decrease across Arizona in the future.

10.4 5-Year Assessment and Monitoring

In accordance with A.R.S. § 49-234, ADEQ will review this TMDL at least once every five years to determine if attainment of applicable WQS has been achieved. This evaluation will determine if the implemented point source controls and voluntary nonpoint source BMPs are successfully reducing Hg in fish tissue or if additional steps should be taken to help expedite progress toward restoring Arizona waters.

Section 11 Public Participation

The development of the TMDL would not have been possible without the participation of the public and the engagement of local interest groups, including representatives from:

- AZGFD
- Arizona State Parks and Trails
- Coconino National Forest
- Apache-Sitgreaves National Forest
- Coronado National Forest
- Prescott National Forest
- Kaibab National Forest
- Tonto National Forest
- Trout Unlimited

The following is a summary of the public and stakeholder engagement efforts for this TMDL:

- **Initial Stakeholder Engagement:** From February 2024 to May 2024, initial meetings with stakeholders were held. These meetings included background information on TMDLs, discussion of the impairments of interest, and desired level of engagement. All of these groups expressed interest in both receiving updates and providing feedback throughout the duration of the Arizona Statewide Mercury TMDL project.
- **Project Updates:** Emails were sent to stakeholders every 30-45 days to provide status updates on the TMDL.

- **Arizona Cross Watershed Lunch ‘n Learn:** On March 5, 2024, members of ADEQ’s Sampling & Source Identification Unit delivered a presentation about ongoing and upcoming TMDL projects — including the Statewide Mercury TMDL — to 38 members of the Arizona Cross Watershed Network as part of that organization’s monthly “Lunch ‘n Learn” series.
- **Arizona Game & Fish Department Annual Expo:** During the spring of both 2024 and 2025, members of ADEQ’s Sampling & Source Identification Unit set up a booth to engage the public at the Arizona Game and Fish Department Annual Expo. Interactive games and a poster were used as engagement tools and provided opportunities to discuss the ongoing Statewide Mercury TMDL and MeHg bioaccumulation in fish in general. It was estimated that ADEQ directly engaged with over 600 people over these two years.
- **Association of Clean Water Administrators Presentation:** On April 25, 2024, members of ADEQ’s Sampling and Source Identification Unit presented their experiences and efforts regarding the ongoing Statewide Mercury TMDL during a Watersheds Committee meeting of the Association of Clean Water Administrators (ACWA). Approximately 70 individuals from around the country were present for this virtual presentation.
- **National Training Workshop on Water Quality Data, Assessment, and Plans:** In June 2025, Clay Mansfield presented ADEQ’s stakeholder engagement efforts for Arizona’s Statewide Mercury TMDL project during a breakout session at an annual national virtual conference hosted by the Environmental Law Institute (ELI).
- **Informal Comment Periods:** Prior to the TMDL formal comment period, ADEQ offered internal and external stakeholders the opportunity to give informal feedback on the draft TMDL. In December 2024, the draft TMDL was reviewed informally by external stakeholders, as well as applicable members of the EPA and ADEQ. An additional informal comment period occurred from July through September 2025 for applicable members of ADEQ and the EPA.
- **Public Comment Period:** The draft TMDL was published on ADEQ’s website on <DATE> for <X> days, and a public notice of publication was prominently placed in <LIST PUBLICATIONS>. During the public notice period, <NUMBER OF COMMENT> public comments were received. The following section summarizes the contents of the public comments and provides responses from ADEQ.

Comment No. 1: <SUMMARIZE COMMENT>

ADEQ Response No. 1: <SUMMARIZE ADEQ’S RESPONSE TO THE COMMENT, INCLUDING ANY CHANGES MADE TO THE DRAFT TMDL AS A CONSEQUENCE.>

Comment No. <X>: <SUMMARIZE COMMENT>

ADEQ Response No. <X>: <SUMMARIZE ADEQ’S RESPONSE TO THE COMMENT, INCLUDING ANY CHANGES MADE TO THE DRAFT TMDL AS A CONSEQUENCE.>

Section 12 Administrative Transparency and Generative AI Disclosure

In accordance with Arizona State Generative AI Policy (P2000), ADEQ utilized the State's governed instance of Google Gemini and NotebookLM during the internal review and finalization of this report. These tools were used by ADEQ staff for supplemental drafting, editorial revising, and the conceptualization of strategic visuals. All generative AI interactions were conducted within a secure, non-training environment where data is not utilized to improve public models. All underlying scientific analysis and data interpretation were performed independently by Tetra Tech and verified by ADEQ staff, who maintain full accountability for the accuracy and regulatory compliance of this report.

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Arizona Statewide Mercury TMDL Development

Technical Support Appendix

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TABLE OF CONTENTS

TABLE OF CONTENTS	I
LIST OF TABLES.....	I
LIST OF FIGURES	II
ABBREVIATED TERMS	III
A-1.0 INTRODUCTION.....	1
A-2.0 ANALYTICAL APPROACH	5
A-3.0 INSTREAM WATER QUALITY TARGETS	6
A-3.1 BAF Analysis: Exposure Targets to Meet Fish Tissue Criterion	6
A-3.2 BAF Analysis Results.....	8
A-3.3 Instream Water Quality Target Selection	15
A-4.0 LANDSCAPE HG TRANSPORT MODELING	16
A-4.1 SPARROW Model Data Processing	17
A-4.1.1 Identifying Downstream COMID for Hg-Impaired Waterbodies.....	17
A-4.1.2 Identifying Upstream COMIDs Draining to Hg-Impaired Waterbodies	17
A-4.1.3 Relating COMIDs to HUC12 Subwatersheds in Hg-Impaired Watersheds	17
A-4.1.4 SPARROW Model Data Gathering	18
A-5.0 POLLUTANT SOURCE INVENTORY	19
A-5.1 Point Sources.....	20
A-5.1.1 Point Sources to Water	20
A-5.1.2 Air Permits.....	25
A-5.2 Nonpoint Sources.....	26
A-5.2.1 Atmospheric Deposition	26
A-5.2.2 Geological Background Erosion.....	33
A-5.2.3 Stream Sediment and Floodplain Sources.....	34
A-6.0 ESTIMATED EXISTING DELIVERED POLLUTANT LOADS	41
A-7.0 ESTIMATED THG CONCENTRATIONS IN IMPAIRED WBIDS.....	47
A-7.1 Predicted THg Concentration Estimates in Impaired WBIDs	47
A-7.2 Calibration to Observed Data.....	48
A-7.2.1 THg Data.....	48
A-7.2.2 Inferred Concentrations from Fish Tissue Data	48
A-7.2.3 Model Calibration	52
A-8.0 LOAD CAPACITIES	54
A-9.0 NEEDED LOAD REDUCTIONS	57
A-10.0 KEY ASSUMPTIONS OF THE TMDL ANALYSIS	60
A-10.1 TMDL Target Specification.....	60
A-10.2 Mass Balance Calculations:	60
A-11.0 REFERENCES.....	61
ADDENDUM A: HG IN WATER ANALYTICAL METHODS.....	63
ADDENDUM B. ANALYSIS FOR LAKE POWELL	64

LIST OF TABLES

Table A-1-1. Arizona water quality standards for Hg and MeHg.....	1
Table A-1-2. List of Hg-impaired waters to be included in the statewide TMDL analysis.	4

Table A-3-1. Aggregated BAFs for each combination of waterbody type, species, and Hg analyte 14

Table A-4-1. SPARROW water balance and suspended sediment variables used in this analysis..... 19

Table A-5-1. List of AZPDES Dischargers Included in the Statewide Hg TMDL Data Analysis..20

Table A-5-2. Active Mines in Arizona, 2022.....24

Table A-5-3. Estimated atmospheric Hg wet deposition (mean rate and total) by land use categories.27

Table A-5-4. THg potency factors to apply in watersheds without site-specific monitoring data.41

Table A-6-1. Average annual total Hg loads delivered to each impaired WBID^a.41

Table A-6-2. Percentage contribution of total Hg sources delivered to each impaired WBID^a. ..44

Table A-7-1. Consensus THg concentration values for calibrating SPARROW model results...49

Table A-7-2. SPARROW model THg calibration.....52

Table A-8-1. Load capacities by WBID.55

Table A-9-1. Needed percent reductions in total Hg loads to achieve TMDL targets.58

LIST OF FIGURES

Figure A-1-1. Map of Hg-impaired waters included in the statewide TMDL analysis.....3

Figure A-3-1. Boxplots of water column MeHg concentrations, by waterbody type..... 8

Figure A-3-2. Boxplots of water column THg concentrations, by waterbody type.....9

Figure A-3-3. Boxplots of fish length by species..... 10

Figure A-3-4. Boxplots of fish tissue Hg concentrations by species. 11

Figure A-3-5. Boxplots of fish tissue Hg concentrations by species and waterbody type. 12

Figure A-3-6. Scatterplots of fish tissue concentration versus fish length by species..... 13

Figure A-5-1. Permitted AZPDES facilities with monitoring requirements for Hg.....23

Figure A-5-2. Average annual Hg wet deposition for Arizona, 2000-2013.....28

Figure A-5-3. Average annual Hg wet deposition for Lake Pleasant (AZL15070102-1100), 2000-2013.29

Figure A-5-4. Lake Pleasant (AZL15070102-1100) runoff-to-precipitation ratios from the USGS WBM.32

Figure A-5-5. MRDS Records of Mines that Produced Gold, Silver, or Hg in Arizona..... 35

Figure A-5-6. MRDS Records of Historic Mines that Produced Hg in Arizona.36

Figure A-5-7. Median THg Potency by HUC12 vs. Cumulative Upstream Mine Index. 38

Figure A-5-8. Individual THg Potency Measurements vs. Cumulative Mine Index.39

Figure A-5-9. Individual THg Potency Measurements vs. Cumulative Mine Index; Stream Samples Only.....40

Figure B-11-1. Lake Powell Location and Drainage Area..... 65

ABBREVIATED TERMS

Acronyms/Abbreviations	Definition
§	Section (usually a section of federal or state rules or statutes)
§ 303(d)	Section 303(d) of the Clean Water Act (Water Quality Impairment list)
§ 502(14)	Section 502(14) of the Clean Water Act (Definition of Point Source)
μ	Micro, one-one thousandth
A&Wc	Aquatic and Wildlife (cold water) Designated Use
A&Ww	Aquatic and Wildlife (warm water) Designated Use
A.A.C.	Arizona Administrative Code
ACCL	Accumulated Streamflow Load
ACCL_S5	Accumulated Load from Alluvial Sources
ACCL_S6	Accumulated Load from Channel Sources
ADEQ	Arizona Department of Environmental Quality
AgI	Agriculture Irrigation Designated Use
AgL	Agriculture Livestock Designated Use
AZPDES	Arizona Pollutant Discharge Elimination System
BAF	Biological Accumulation Factor
CCF	Channel Catfish
CFR	Code of Federal Regulations (refers to citations in the federal administrative rules)
cfs	Cubic Feet per Second
cm	Centimeter
CWA	Clean Water Act
CVAA	Cold Vapor Atomic Absorption
COMID	Common Identifier
DMGP	De Minimis General Permits
DMR	Discharge Monitoring Report
dMeHg	Dissolved MeHg
DOI	United States Department of the Interior
EPA	United States Environmental Protection Agency
FC	Fish Consumption Designated Use

Acronyms/Abbreviations	Definition
FHC	Flathead Catfish
FBC	Full Body Contact Designated Use
GIS	Geographic Information System
Hg	Hg
HUC	Hydrologic Unit Code
IncAreaKm2	Incremental Drainage Area (km ²)
Incusarkm2	Incremental Drainage Area in the U.S. (km ²)
INCL	Incremental Streamflow
INCL_S5	Incremental Load from Alluvial Sources
INCL_S6	Incremental Load from Channel Sources
KD	Partition Coefficient
LMB	Largemouth Bass
LA	Load Allocation
lb	Pound
LC	Load Capacity
MeHg	Methylmercury
mi	Mile
MI	Mining Index (count of Au, Ag, and Hg mines per square kilometer area)
mg/kg	Milligrams per Kilogram
mg/L	Milligrams per Liter
mL	Milliliter
mm	Millimeter
MOS	Margin of Safety
MS4	Municipal Separate Storm Sewer System
NA	Not Applicable
NADP-MDN	National Atmospheric Deposition Program Hg Deposition Network
ng/L	Nanograms per Liter
NLCD	National Land Cover Dataset
Non-POTW	Facility not designated as a publicly owned treatment works
NPDES	National Pollutant Discharge Elimination System

Acronyms/Abbreviations	Definition
POTW	Publicly Owned Treatment Works
PRISM	Parameter-elevation Relationships on Independent Slopes Model
REMSAD	Regional Modeling System for Aerosols and Deposition
RL	Reporting Limit
SPARROW	SPATIally Referenced Regression on Watershed attributes
SUN	Sunfish Species
TMDL	Total Maximum Daily Load
THg	Total Hg
TRI	Toxics Release Inventory
TSS	Total Suspended Solids
USGS	United States Geological Survey
VBA	Visual Basic for Applications
WBID	Waterbody Identifier
WNAM	Western North American Hg Project
WBM	Water-Balance Model
WWTP	Wastewater Treatment Plant

A-1.0 INTRODUCTION

Several lakes and streams within the state do not meet Arizona’s water quality standards for mercury (Hg) and are listed on Arizona’s Clean Water Act (CWA) Section § 303(d) list of waters requiring the development of a Total Maximum Daily Load (TMDL) (Figure A-1-1). Hg is a naturally occurring element that cycles through the atmosphere, hydrosphere, and biosphere. Contaminant sources can include point sources, nonpoint sources, and background geogenic Hg. Legacy mining activities that used Hg for extracting gold and silver from ore and placer deposits are often a major source of Hg pollution in mining areas of the western United States. Hg is also emitted into the atmosphere by local, regional, and global sources, such as coal-fired power plants, concrete production, volcanoes, and metal processing operations. These atmospheric sources can redeposit Hg to the land surface or direct to waterbodies. Environmental processes, such as iron and sulfate reduction by bacteria in sediments, support complex biogeochemical processes that convert inorganic Hg to the organic form methylmercury (MeHg). Filter-feeding organisms then ingest MeHg, leading to bioaccumulation up the food chain. Humans and wildlife primarily gain exposure to Hg by eating contaminated fish and shellfish. Hg is toxic to human and wildlife nervous systems (USEPA, 2001).

As specified in the Arizona Administrative Code (A.A.C) R-18-11 Appendix A, waterbody designated uses affected by Hg in Arizona include cold and warm water aquatic and wildlife (A&Wc and A&Ww, respectively), full body contact (FBC), fish consumption (FC), agricultural livestock watering (AgL), and agricultural irrigation (AgI). Water quality standards are designed to protect designated uses (Table A-1-1). Arizona’s Hg water quality standards are expressed as water column concentrations (micrograms of total Hg (THg) per liter; µg/L) and fish tissue Hg levels (milligrams of MeHg per kilogram of tissue; mg/kg). Waterbodies that do not meet water quality standards are identified by states based on monitoring. Hg is a parameter impairment in 31 of Arizona’s waterbodies (Table A-1-2), posing risks to human health and the environment. Except for Mineral Creek (15050100-012B) and Devils Canyon (15050100-1662), which are only impaired due to excursions of the chronic ambient water quality criteria for Hg, the remainder of Arizona’s Hg impairments are due to elevated MeHg levels in fish tissue.

Table A-1-1. Arizona water quality standards for Hg and MeHg.

Pollutant Form	Designated Use	Criterion	Chemical Form
Hg	Aquatic and Wildlife (warm water, A&Ww; cold water, A&Wc)	acute: 2.4 µg/L chronic: 0.01 µg/L	dissolved dissolved
	Full Body Contact (FBC)	280 µg/L	total recoverable
	Agricultural Irrigation (AgI)	No numeric criterion	n/a
	Agricultural Livestock Watering (AgL)	10 µg/L	total recoverable
MeHg	Fish Consumption (FC)	0.3 mg/kg	fish tissue ^a

a. ADEQ reports that fish tissue samples are based on analysis of skin-on fillets. A very small number of skin-off fillets were present in the database, so they were filtered out of the analysis described in Section A-3.0.

ADEQ has developed a statewide TMDL to address Hg-impaired waters across the state. There are existing EPA-approved Hg TMDLs for some of the waterbodies included in Table A-1-2, but they are being updated and revised with the findings of the statewide TMDL. The statewide TMDL will leverage historic and recent Hg data collected in Arizona. This memorandum summarizes the results of the technical assessment of the statewide Hg TMDL.

Lake Powell (14070006-1130) requires special consideration in the statewide TMDL due to its size (252 square miles) and the fact that much of its drainage area and surface lie outside Arizona's jurisdiction. Additionally, ADEQ has not collected fish tissue Hg data for the portion of Lake Powell within Arizona. The lake was listed as impaired on Arizona's 303(d) list in 2010 based on Hg concentrations in fish tissue sampled by Utah, where Hg levels in striped bass exceeded the Arizona fish tissue criterion of 0.3 mg/kg.

The majority of Lake Powell's Hg load comes from outside Arizona. Specifically, Utah's fish tissue data from 2005 to 2010 showed Hg concentrations ranging from 0.301 to 1.3 mg/kg in striped bass, with a median of 0.424 mg/kg. These results indicate elevated Hg concentrations across Utah's portion of the lake, but Arizona has not collected water column Hg samples in Lake Powell, preventing a direct BAF analysis. Instead, reductions were estimated using the Reduction Factor method, yielding a 32.3% reduction requirement based on the median Hg concentration in Utah's striped bass samples. Refer to Addendum B for a more detailed discussion of the limitations of including Lake Powell in the statewide TMDL approach, as well as the data analyses conducted using Utah's fish tissue Hg data and the methods applied to estimate Hg reductions for this waterbody.

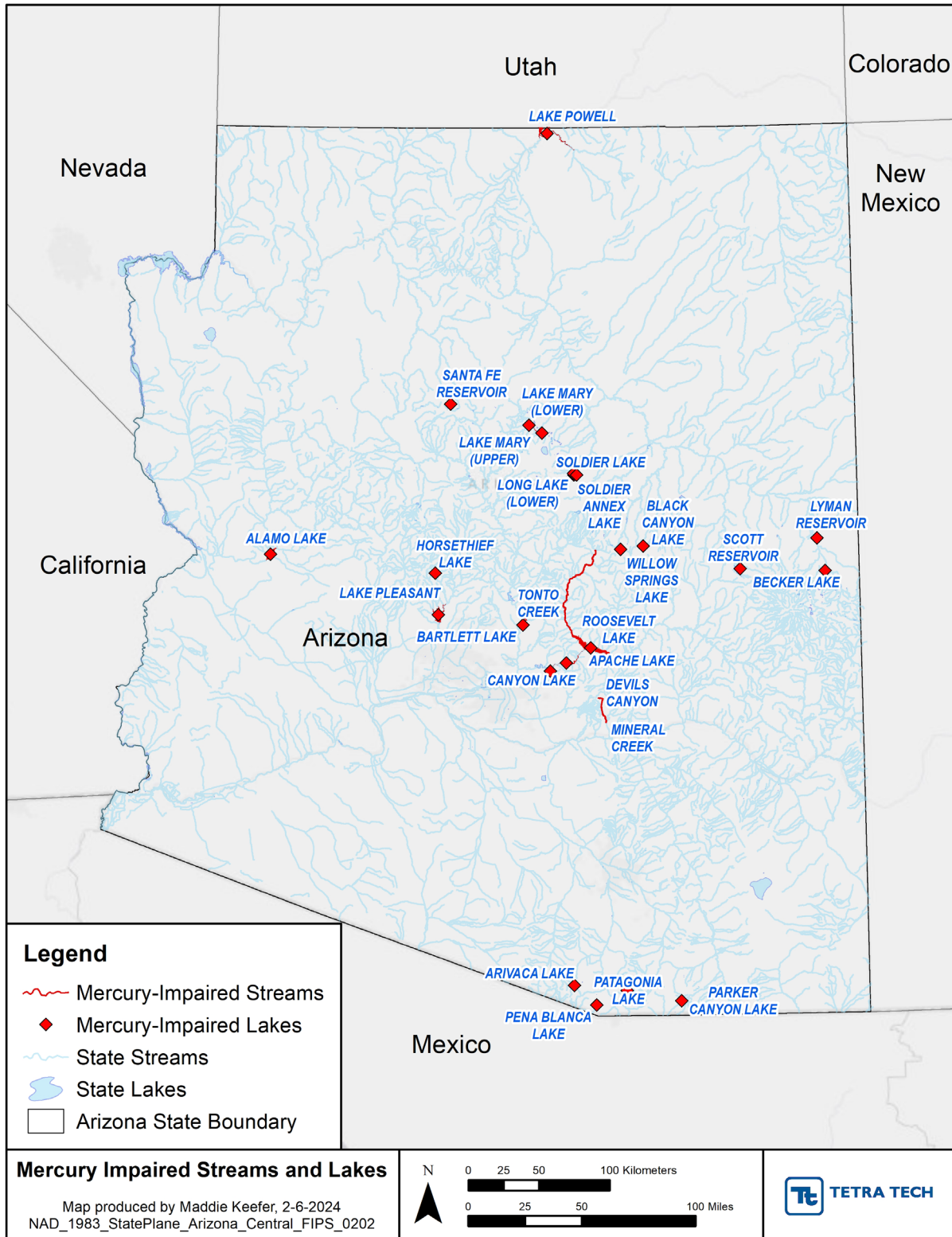


Figure A-1-1. Map of Hg-impaired waters included in the statewide TMDL analysis.

Table A-1-2. List of Hg-impaired waters to be included in the statewide TMDL analysis.

Reach ID	Location	Original 303(d) Listing Date	TMDL Revision?
15050301-1070	Peña Blanca Lake	7/1/1996	Revision
15050304-0080	Arivaca Lake	7/1/1996	Revision
15020015-0890	Lake Mary (Lower)	7/1/2002	Revision
15020015-0900	Lake Mary (Upper)	7/1/2002	Revision
15020008-0820	Long Lake (Lower)	7/1/2004	Revision
15020008-1430	Soldiers Annex Lake	7/1/2004	Revision
15020008-1440	Soldiers Lake	7/1/2004	Revision
15020001-0850	Lyman Reservoir	7/1/2004	New TMDL
15030204-0040A	Alamo Lake	7/1/2004	New TMDL
15050301-1040	Parker Canyon Lake	7/1/2004	New TMDL
15060106A-0250	Canyon Lake	7/1/2004	New TMDL
15060103-1240	Roosevelt Lake	7/1/2008	New TMDL
15070102-1100	Lake Pleasant	7/1/2008	New TMDL
14070006-1130	Lake Powell	7/1/2010	New TMDL
15020010-0180	Black Canyon Lake	7/1/2010	New TMDL
15060105-004	Tonto Creek	7/1/2010	New TMDL
15060105-006	Tonto Creek	7/1/2010	New TMDL
15060105-008	Tonto Creek	7/1/2010	New TMDL
15060105-009	Tonto Creek	7/1/2010	New TMDL
15060105-011	Tonto Creek	7/1/2010	New TMDL
15060105-013B	Tonto Creek	7/1/2010	New TMDL
15060106A-0070	Apache Lake	7/1/2016	New TMDL
15060203-0110	Bartlett Lake	7/1/2016	New TMDL
15020001-0150	Becker Lake	8/28/2017	New TMDL
15020005-1360	Scott Reservoir	5/18/2018	New TMDL
15020010-1670	Willow Springs Lake	5/18/2018	New TMDL
15010004-1340	Santa Fe Reservoir	1/28/2020	New TMDL
15070102-0630	Horsethief Lake	1/28/2020	New TMDL
15050100-1662	Devils Canyon	8/5/2021	New TMDL

Reach ID	Location	Original 303(d) Listing Date	TMDL Revision?
15050100-012B	Mineral Creek	8/16/2021	New TMDL
15050301-1050	Patagonia Lake	8/5/2024	New TMDL

A-2.0 ANALYTICAL APPROACH

The analytical workflow of the Data Analysis phase of the AZ statewide Hg TMDL project, which is repeated for each identified Hg impairment, involves five main components. These components are described briefly in this section (Section A-2.0) and are expanded on in later sections of this report. By following this comprehensive and detailed approach, the development of Hg TMDL calculations for Arizona aims to ensure that water quality standards for Hg are met while considering the unique environmental and hydrological characteristics of the state's water bodies.

1. Select Total Mercury (THg) Target:

- a. The TMDL target for most of the Hg impairments is driven by the fish tissue criterion, which must be translated into a water column target. Two stream impairments, Devils Canyon and Mineral Creek, are listed because of excursions of the chronic ambient water quality criterion of 0.010 µg/L (10 ng/L) and not for fish tissue concentrations.
- b. Statewide Hg bioaccumulation factors (BAFs) that describe the relationship between fish tissue concentrations and water column concentrations are calculated for different fish species and waterbody types. These BAFs are translated into ambient THg concentration targets in water.
- c. The THg targets are cross-checked with existing Arizona ambient water quality criteria. If there are cases where the ambient criterion is more restrictive than the BAF-based target, the more stringent criterion applies.

2. Determine Reduction Factor (RF):

- a. Site-specific TMDL reduction factors are determined in two ways: (a) by comparing fish tissue concentrations to fish tissue targets and (b) by comparing observed water column THg concentrations to the THg target determined in Step 1.
- b. This dual approach ensures that unique characteristics of individual impairments are addressed accurately. If the two estimates are not in reasonable agreement additional investigation may be needed regarding the amount and quality of data or special circumstances for a specific impairment.

3. Calculate Existing THg Loading:

- a. Loading analysis is conducted on a USGS Hydrologic Unit Code – 12 digit (HUC12) basis for all subwatersheds draining to a Hg-impaired waterbody, including considerations for transit losses, dry atmospheric deposition, wet deposition in

overland runoff, point sources, geological background erosion, and near-channel sources.

- b. Transit losses are estimated based on SPARROW model outputs for flow and sediment transport.

4. Estimate Concentration and Adjust to Data:

- a. Estimated loads determined in Step 3 are converted to steady-state concentration estimates for each impairment, considering average volume and residence time in lakes.
- b. Comparisons between estimated and observed concentrations are made, with adjustments introduced if significant discrepancies are found. For example, in Peña Blanca Lake, the SPARROW analysis predicted an average THg concentration of 16.1 ng/L, but the observed average is 6.5 ng/L, which is more consistent with the observed fish tissue concentrations. Therefore, the net THg lake loss rate (due to sedimentation, precipitation of cinnabar, and other factors) was increased to bring SPARROW estimates into agreement with the other lines of evidence (see Section A-7.0 for further details).
- c. As part of this step, we also summarize loads by sources, including identification of sources not controllable by ADEQ such as natural background loading and long-range atmospheric deposition loads.

5. Estimate TMDL by Applying Reductions:

- a. The TMDL loading capacity is estimated by applying reduction factors to existing loads. The feasibility of reductions is assessed, ensuring that load reductions are within natural background levels and uncontrollable sources external to Arizona.
- b. Because Hg bioaccumulation is a long-term, chronic process the loading capacity is equivalent to a long-term average THg load target. Court rulings have held that a TMDL must be stated in terms of daily loads and point source permits also typically include a not-to-exceed criterion. Maximum allowable daily or monthly loads are estimated based on statistical relationships between average and maximum concentrations.

A-3.0 INSTREAM WATER QUALITY TARGETS

Hg-related impairments in Arizona are assessed in two ways. First, the waterbody total Hg concentration may exceed the ambient water quality criterion of 10 ng/L. The target for that case is already specified in the regulation.

Second, Hg-related impairment may occur because fish tissue concentrations exceed guidelines for the protection of human health. Establishing water column concentration targets for the second case requires establishing a relationship between fish tissue concentrations and ambient Hg exposure concentrations. This was done (consistent with USEPA 2001 and 2010) through a bioaccumulation factor (BAF) analysis.

A-3.1 BAF ANALYSIS: EXPOSURE TARGETS TO MEET FISH TISSUE CRITERION

The purpose of the BAF analysis is to establish a statistical relationship that represents the bioaccumulation of Hg in fish tissue based on water column Hg concentrations. The modeled

relationship can then be used to establish an instream water column target to ensure tissue levels in consumable fish are consistent with Arizona guidance for the protection of human health. Process-based models of bioaccumulation of Hg by fish are available, but the high complexity of describing all the food web pathways has large data requirements for species bioenergetics, including in lower trophic levels, that are difficult to obtain. Without such data, simpler empirical approaches, which implicitly incorporate the food web complexities, have proved more robust.

In higher trophic level fish, such as largemouth bass and other gamefish that are frequently consumed by humans, most of the Hg burden consists of MeHg. This is because the organic compound MeHg is retained in the food chain and tends to accumulate at higher levels at higher trophic levels (i.e., predatory fish that eat other, lower-trophic level fish) and the MeHg burden in fish tissue can be assumed to be approximately equal to the THg burden (USEPA, 2010). MeHg exposure concentrations in water are often near analytical detection limits and can be highly variable in time due to bacterial and physical processes that convert between the organic and inorganic forms of Hg. In addition, MeHg has been less frequently monitored than THg and discharge requirements on point sources are typically expressed in terms of THg. Therefore, the analysis for this TMDL is expressed in terms of THg, recognizing that the relationship between THg and MeHg may vary according to site-specific factors.

The relationship between exposure concentrations of THg or MeHg and fish tissue concentrations tends to be highly variable, particularly in streams where fish may move between habitats according to season. For this reason, estimates of target concentrations of THg in water to achieve fish tissue criteria are uncertain. USEPA (2010) recommends using a BAF approach and developing an ambient water quality criterion (i.e., a TMDL target) by dividing the target tissue concentration by the BAF. For extrapolation across multiple sites EPA recommends use of the geometric mean of BAFs from individual sites as the best indicator of central tendency that is not unduly influenced by anomalous outliers. These BAFs are derived as the ratio of median fish tissue concentration (after conversion to a standard length) to median water column Hg concentrations. The median rather than the average is used to reduce bias introduced by anomalous outliers in small data sets and because the underlying distribution of fish tissue concentrations is anticipated to follow a log-normal distribution, for which the median is an unbiased estimate of central tendency.

The BAF approach used in the Arizona statewide Hg TMDL involves using fish tissue data collected in the project area to determine a relationship between ambient THg, fish length (i.e., a surrogate for age and accumulation timespan), and tissue THg concentrations for the target endpoint species. Food webs across the state may differ. Therefore, different environment-specific (e.g., lake versus stream) relationships and BAFs are derived to account for these differences. In Arizona, nearly all lakes are manmade formations created by damming streams or rivers, making the terms "lake" and "reservoir" functionally interchangeable. For clarity, they will be collectively referred to as "lake/reservoir" throughout this document.

We undertook a comprehensive analysis of the water column/sediment and fish tissue Hg linkage using data collected across the state's Hg-impaired waterbodies. Samples collected at impaired waterbody sites are averaged by type (e.g., fish tissue) and then paired for model development. The higher trophic level endpoint fish species that are included in the current TMDL assessment are the largemouth bass (LMB), channel catfish (CCF), and flathead catfish (FHC), which are Trophic Level 4 (top predator) species in these aquatic environments. Many measurements are also reported for Trophic Level 3 species (bluegill, redear sunfish, and green

sunfish), which are grouped as sunfish (SUN), but are expected to have lower Hg body burdens due to their lower trophic position.

A-3.2 BAF ANALYSIS RESULTS

For observations of MeHg in the water column, the concentrations are roughly 1.5 orders of magnitude smaller than water THg values. Concentrations for lake/reservoir waterbodies are lower than stream waterbody values on average, with samples for steam waterbodies spanning the widest range of values as shown in Figure A-3-1.

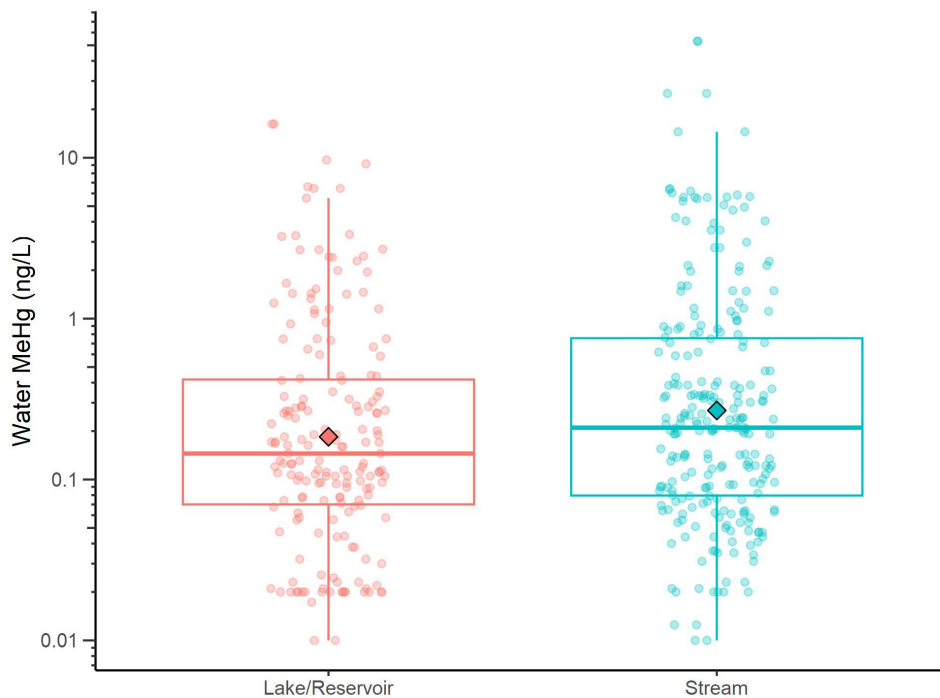


Figure A-3-1. Boxplots of water column MeHg concentrations, by waterbody type. Top and bottom of box denote the 75th and 25th percentiles. Thick horizontal line denotes the median. The vertical lines extend to “1.5 * (75th - 25th percentile)”. Colored diamonds denote geomeans.

Regarding water column observations of THg, the central tendencies are similar for lake/reservoir and stream data (Figure A-3-2). Water column data from stream waterbody types display the largest variation, with many samples above the chronic criterion (10 ng/L) and some samples above the acute criterion of 2,400 ng/L.

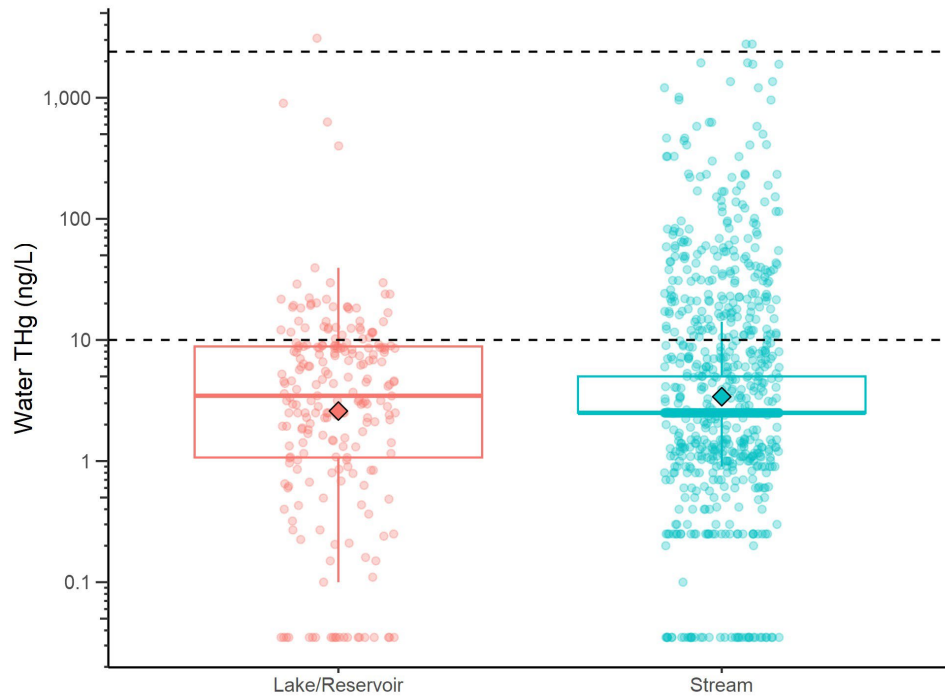


Figure A-3-2. Boxplots of water column THg concentrations, by waterbody type. Horizontal dashed lines denote the EPA promulgated chronic and acute criteria for Hg in water for AZ (10 ng/L and 2,400 ng/L, respectively).

For fish data, there are fewer samples for FHC compared to SUN and CCF, with LMB having the most samples (34, 90, 109, and 540 samples for flathead catfish, sunfish/bluegill, channel catfish, and largemouth bass, respectively) (Figure A-3-3). Fish length (a proxy for age) varies, with FHC overall being the longest, followed by CCF, and LMB, with SUN being the shortest overall. The median lengths for each species are as follows: FHC at 620 mm (24.4 inches), CCF at 429 mm (16.9 inches), LMB at 343 mm (13.5 inches), and SUN at 191 mm (7.5 inches). The variance in length was larger for LMB, which is likely due to the notably larger sample size.

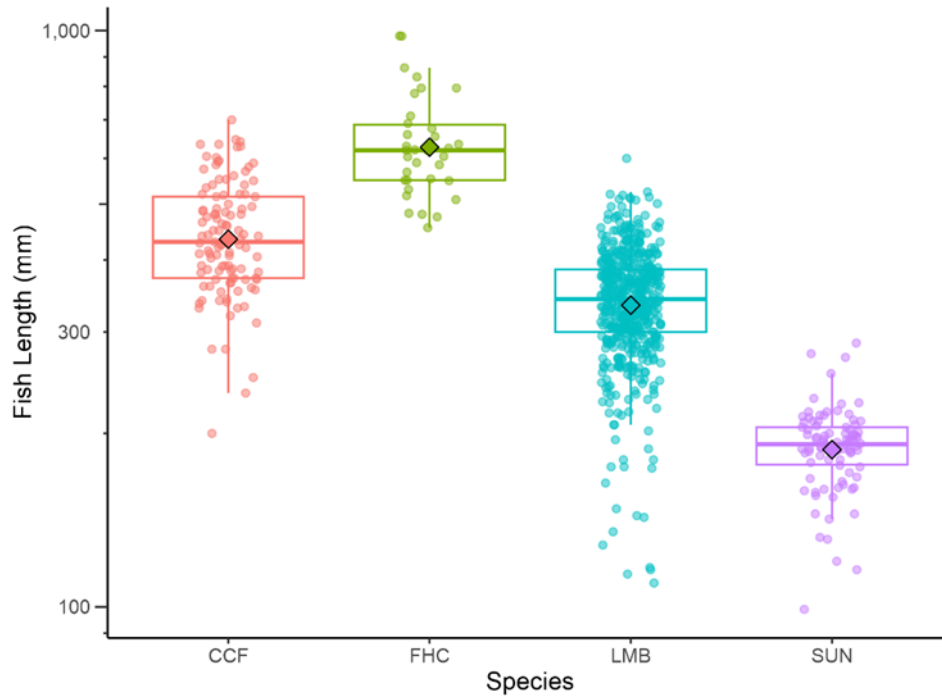


Figure A-3-3. Boxplots of fish length by species.

Investigating fish tissue concentration data, CCF is observed to have the lowest concentrations of the fish species of interest, followed by FHC, and SUN, with LMB having the largest fish tissue Hg concentrations overall as shown in Figure A-3-4 (median values of 0.28, 0.31, 0.35, and 0.52 mg/kg, respectively). For reference, the current AZ fish tissue Hg criterion is 0.30 mg/kg. Roughly half of the samples from these four species exceed this 0.30 mg/kg criteria, with exceedance percentages of 45.9%, 50.0%, 61.1%, and 69.9% for CCF, FHC, SUN, and LMB respectively.

Looking at fish data by waterbody type, there are fewer stream samples than lake/reservoir samples, with the total number of samples from lake/reservoir waterbodies far exceeding the count for stream waterbody type samples (42 samples for streams and 712 samples for lake/reservoir waterbodies). Fish tissue concentrations for lake/reservoir samples are significantly more varied than stream samples, likely due to the large sample size for lake/reservoir waterbody types.

Fish tissue concentrations vary across both species and waterbody (Figure A-3-5), suggesting that the interaction between species and waterbody type should be considered. Stream samples show lower fish tissue concentrations for channel catfish (CCF) and flathead catfish (FHC), compared to lake/reservoir samples, with lake/reservoir samples having the largest tissue concentrations for channel and flathead catfish species. Largemouth bass (LMB) fish tissue Hg concentrations have similar central tendencies across waterbody types, with higher concentration samples observed in streams compared to lake/reservoir samples. Sunfish (SUN) also show similar central tendencies for lakes/reservoirs and streams.

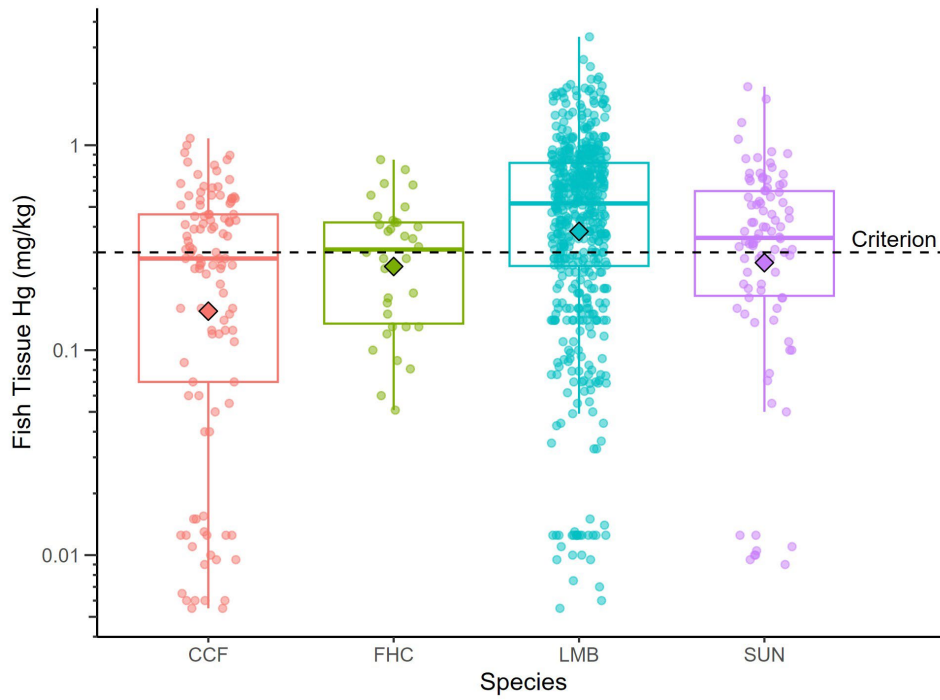


Figure A-3-4. Boxplots of fish tissue Hg concentrations by species. The horizontal dashed line denotes the Arizona fish tissue criterion (0.3 mg/kg).

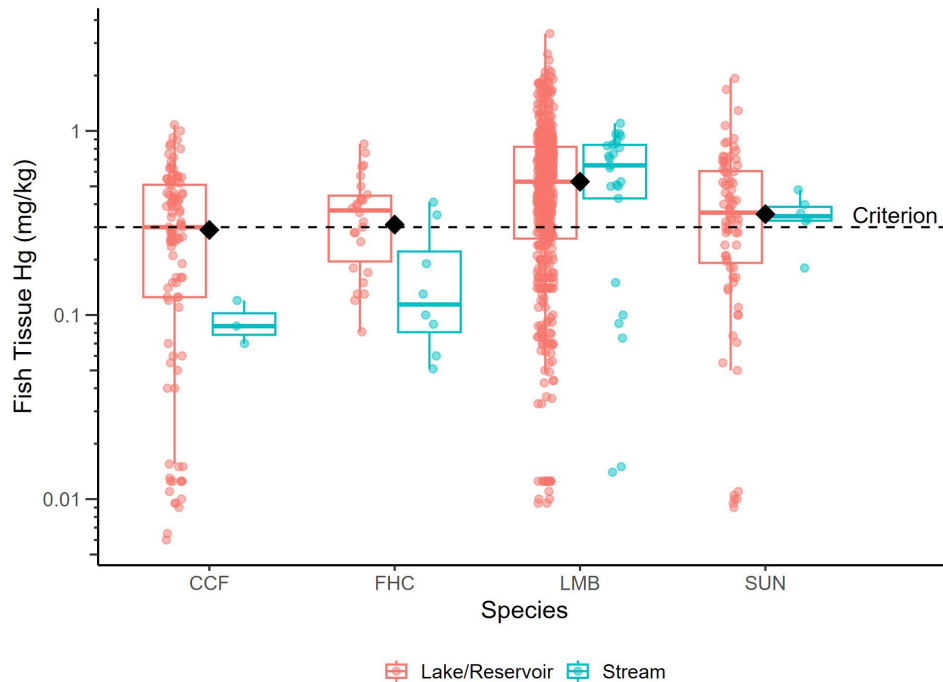


Figure A-3-5. Boxplots of fish tissue Hg concentrations by species and waterbody type. Black diamonds denote the median concentration across all waterbody types. The horizontal dashed line denotes the Arizona fish tissue criterion (0.3 mg/kg).

Because Hg bioaccumulates within the fish tissue with age, tissue concentrations are standardized by specimen length (a proxy for age) to account for samples collected across a range of younger or older specimens. The median values of the species samples were used as the standard length.

Separately for each species, linear regression is used to standardize fish tissue concentrations using the following equation:

$$\ln(\text{FishTissueConc}_i) = \text{Intercept} + B * \text{FishLength}_i + e_i$$

where i is a sample index, *Intercept* and B are parameters estimated by the model, and e is the residual error. The response is (natural) log transformed to guarantee a positive value for the standardized concentration. The residual errors for the CCF, FHC, LMB, and SUN species models are 1.557, 0.741, 1.174, and 1.240, respectively (all in log-space since the response is log-transformed). The standardized concentration is:

$$\text{StdTissueConc}_i = \text{PredTissueConcAtStdLength} + \text{Resid}_i$$

where i is the sample index, *StdTissueConc* is the sample's standardized concentration, *PredTissueConcAtStdLength* is the predicted concentration at the standard length, and *Resid* is the sample's residual from the linear regression. Visually, this equates to "sliding" the data point

parallel to the line of best fit, toward the standard length (Figure A-3-6). The standardized tissue concentration is then back-transformed as the final step. Figure A-3-6 shows the data and regression fits for each species of interest. The regression slopes were not significant at the 0.05 level due to the relatively large amount of scatter seen in the data.

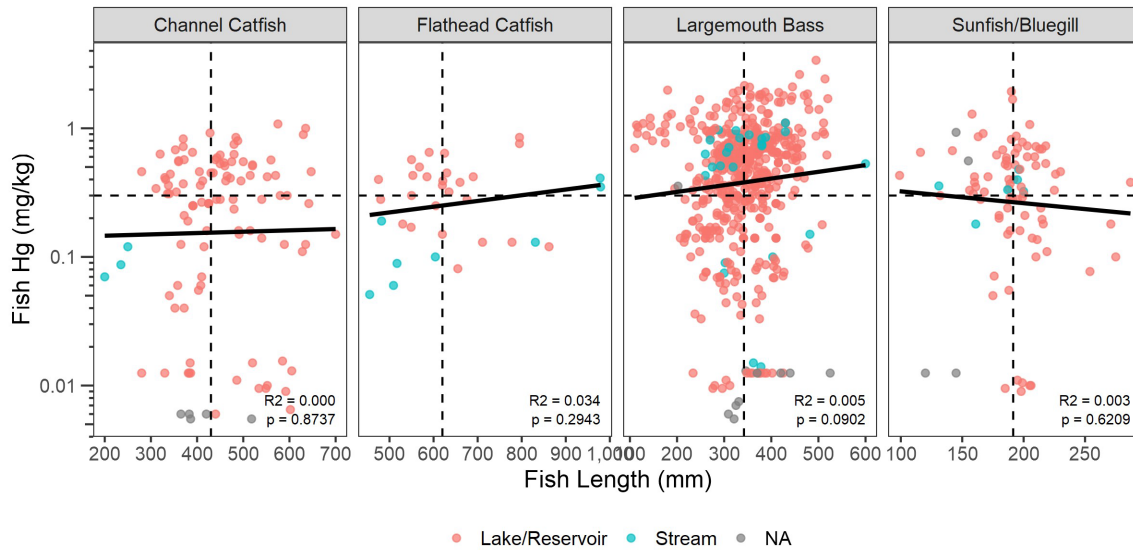


Figure A-3-6. Scatterplots of fish tissue concentration versus fish length by species. Points are color-coded by waterbody type. Solid lines denote the line of best fit, vertical dashed lines denote species standard length, and horizontal dashed lines denote the Arizona fish tissue criterion (0.3 mg/kg).

Bioaccumulation factors (BAFs) are calculated for various groupings of waterbody type and fish species of interest. BAF for THg or MeHg is estimated for a given site’s set of fish tissue and exposure concentrations, consistent with EPA (2010) guidance, as:

$$BAF = \frac{MedianFishTissueConc}{MedianWaterConc}$$

where fish tissue is measured in mg/kg, water concentration is ng/L, and BAF is "L/kg * 10^6". A larger BAF is more conservative.

For Arizona, we first calculate the BAF for each unique waterbody ID (WBID), fish species, and Hg type combination with available data. There are 154 combinations with fish tissue data and 1,048 combinations with water Hg data. Out of those, only 69 combinations have both fish tissue and water column Hg data allowing for a BAF to be calculated. Those 69 combinations represent data collected from 21 unique WBIDs.

We then aggregate (using the geomean) the WBID-specific BAFs by waterbody type (lakes, reservoirs, streams, and all waters), by fish species (CCF, FHC, LMB, SUN, and all species), and by water column Hg species (THg vs. MeHg). This results in 35 different combinations to

explore. USEPA (2010) recommends using a BAF approach and developing an ambient water quality criterion (i.e., a TMDL target) by dividing the target tissue concentration by the BAF. The document also recommends normalization to a standard length and calculating the BAF as the ratio of tissue concentration to water column exposure concentration. For extrapolation across multiple sites, EPA recommends the use of the geometric mean as the best indicator of central tendency. The method is specifically recommended for use with dissolved MeHg (dMeHg) concentrations in the water column but notes that a translator between THg and dMeHg may be used when sufficient dMeHg data are not available. The calculation of national geometric mean translators is shown in Appendix A and Table A-10 of the MeHg criterion document (USEPA 2001) where the translator between dMeHg and THg is referred to as a “pseudo K_D ” because it has the same mathematical form as a partition coefficient (K_D) between dissolved and total concentrations of a single contaminant. In general, K_D is equal to the ratio of the particulate-sorbed concentration (C_p) normalized to the solids concentration (TSS) and the dissolved concentration (C_d): $K_D = C_p / (C_d \times TSS)$. The total concentration (C_t) is then $C_t = C_p + C_d = C_d (1 + K_D \times TSS)$ and the ratio C_d / C_t is $(1 + K_D \times TSS)^{-1}$.

For the pseudo K_D relating dMeHg to THg this is interpreted as $dMeHg / THg = (1 + pseudo-K_D \times TSS)^{-1}$. Taking the geometric mean over samples obtained from many different systems with different TSS levels, EPA (2001) estimated the \log_{10} pseudo K_D for dMeHg/THg in lentic systems (lakes and reservoirs) as 6.83 and the corresponding ratio of dMeHg to THg as 0.032. For lotic systems (streams and rivers) the pseudo $\log K_D$ proposed by EPA (2001) is 6.44 and the ratio of dMeHg to Hg is 0.014,

Summaries of aggregated BAFs are shown in Table A-3-1. BAFs calculated with water column observations of MeHg are roughly an order of magnitude larger compared to those using water column THg as the inputs for BAF calculations. This is because MeHg is the form of Hg that bioaccumulates and MeHg observations in the water column are roughly 1.5 orders of magnitude smaller than THg concentration samples.

BAFs are traditionally reported in units of L/kg based on dividing mg/kg in fish tissue by mg/L in water, so ratios based on water concentrations in ng/L must be multiplied by 10^6 to convert mg to ng. Aggregated BAFs range from 0.037×10^6 to 0.86×10^6 L/kg for THg and from 0.028×10^6 to 7.68×10^6 L/kg for total MeHg. Sufficient data are not available with low enough detection limits to calculate BAFs for dMeHg. Stream waterbody sites have lower BAF values compared to lake/reservoir waterbody sites. Flathead catfish (FHC) have the largest BAFs, followed by largemouth bass (LMB). LMB samples from lake/reservoir waterbodies have the largest sample size with data available for 15 WBIDs.

Table A-3-1. Aggregated BAFs for each combination of waterbody type, species, and Hg analyte (calculated using the geomean of the dataset).

Waterbody Type	Fish Species	# of Waterbodies for THg	BAF (L/kg) for THg	# of Waterbodies for MeHg	BAF (L/kg) for MeHg	THg Target (ng/L)
Lake/Reservoir	CCF	9	0.13×10^6	9	3.80×10^6	2.350
	FHC	2	0.86×10^6	2	7.68×10^6	0.350
	LMB	15	0.22×10^6	15	2.87×10^6	1.346
	SUN	6	0.15×10^6	6	1.09×10^6	2.073

Waterbody Type	Fish Species	# of Waterbodies for THg	BAF (L/kg) for THg	# of Waterbodies for MeHg	BAF (L/kg) for MeHg	THg Target (ng/L)
Stream	CCF	1	0.15 x 10 ⁶	0	--	1.974
	FHC	1	0.04 x 10 ⁶	0	--	7.268
	LMB	1	0.04 x 10 ⁶	1	0.13 x 10 ⁶	8.068
	SUN	0	--	1	0.03 x 10 ⁶	ND

A-3.3 INSTREAM WATER QUALITY TARGET SELECTION

TMDL water quality targets are a translation of the applicable numeric or narrative water quality standard(s) for each pollutant. Water quality targets are typically developed for multiple parameters that link directly to the impaired beneficial use(s) and applicable water quality standard(s). Therefore, the targets provide a benchmark by which to evaluate the attainment of water quality standards. Furthermore, comparing existing waterbody conditions to target values allows for a better understanding of the extent and severity of the problem.

Arizona water quality standards for Hg are discussed above in Section A-1.0 and Table A-1-1. For the purposes of the statewide TMDL, the fish tissue concentration targets need to be translated into instream total Hg concentration and load targets. This TMDL uses a bioaccumulation factor (BAF) approach to translate the fish tissue target to an instream Hg concentration target as recommended in EPA’s (2010) guidance for implementing the 2001 MeHg criteria recommendations. Section A-3.0 provides details of the bioaccumulation analysis.

Water column Hg concentration targets can be calculated in two ways:

- 1) Water Target = (1 – Reduction Factor) * Geomean of Observed Water Column Concentrations, where Reduction Factor = (Median Fish Tissue Concentration – Target Fish Tissue Concentration)/Median Fish Tissue Concentration
- 2) Water Target = Target Fish Tissue Concentration / Bioaccumulation Factor (BAF)

When using only paired data for water column and fish tissue Hg concentrations for individual sites, the two options yield exactly the same results. However, discrepancies can arise when aggregating data to represent multiple waterbodies, as there are often sites that have fish tissue concentration data but no corresponding valid water column data. For example, there are 14 impaired lake sites in Arizona with both water column and fish tissue Hg concentration data; however, there are 35 unique lake waterbody sites that have fish tissue data but no accompanying water column THg data. BAFs can only be calculated using sites with paired data for water column and fish tissue Hg concentrations, but Reduction Factors (RFs) can be calculated for sites that do not necessarily have paired data.

THg concentrations in water can be highly variable from year to year in Arizona’s climate. Therefore, we select option (2), where the water column target concentration is calculated from aggregated BAF estimates rather than applying option (1) as extra samples used in calculating Reduction Factors may have been collected in seasons or years when exposure concentrations were much lower. We apply the targets and percent reductions calculated from the fish tissue concentration target (0.3 mg MeHg/kg) and the aggregated BAFs presented in Table A-3-1 that

were calculated for each waterbody type, species of interest, and Hg analyte combination using the geomean of the dataset. For the load capacity analyses, we applied the central tendency of the water column THg target estimates for lakes and reservoirs from CCF, FHC, and LMB. Sunfish (SUN) species were omitted from the central tendency calculation as they are not trophic level 4 species. The average of the BAF-calculated THg targets for lake/reservoir waterbodies is 1.349 ng/L. However, for streams, the very limited data availability of stream sites with paired fish tissue and water column Hg data suggested it is more appropriate to use the most restrictive stream target from Table A-3-1 (1.974 ng/L) for the load capacity analyses.

The two downstream segments of Tonto Creek (AZ15060105-004 and AZ15050105-006) are considered to be a special case. Segment 004 is within the normal pool of Lake Roosevelt and segment 006 ends at Lake Roosevelt; therefore, these segments are expected to have characteristics intermediate between free-flowing stream and lake conditions, and the lake target is assigned as it is more protective.

A-4.0 LANDSCAPE HG TRANSPORT MODELING

The Spatially Referenced Regressions on Watershed Attributes (SPARROW) model outputs for the Southwestern United States were used as an efficient way to estimate flow and sediment loads for Arizona (Wise et al., 2019 and Miller et al., 2020). SPARROW is an environmental model developed by the USGS to estimate nutrient loads and yields in freshwater systems. The SPARROW model incorporates information on flow and precipitation along with sediment and nutrient transport and is a useful platform for exercises such as the statewide Hg TMDL. It also provides a consistent methodology for extrapolation to waterbodies that have limited or no flow and monitoring data. The model is used to assess the sources, transport, and delivery of nutrients from watersheds to streams, rivers, and lakes. Published SPARROW model outputs and results are calibrated and validated using observed flow and nutrient data from local monitoring stations. The associated data release for the Southwest SPARROW model was revised in October 2020 and provides both incremental and accumulated flow and sediment load for each National Hydrography Dataset Plus version 2 (NHDPlusV2) reach and catchment. (SPARROW uses an enhanced version of NHDPlus [E2NHDPlus2; Brakebill et al., 2020] that incorporates various routing corrections.)

SPARROW simulates average annual flow along with sediment and nutrient transport consistent with 2012 land use conditions and point sources. Flow is estimated using the United States Geological Survey (USGS) Water-Balance Model (WBM), which uses high-resolution gridded meteorological data (Wieczorek et al., 2024). The SPARROW model output provides the total accumulated flow, sediment load, and nutrient load at each stream node in NHDPlusV2 (variable name ACCL; Table A-4-1) as well as the incremental load derived from the local catchment for each segment (variable name INCL). SPARROW also predicts accumulated and incremental sediment load derived from channel and near-channel alluvial erosion processes (ACCL_S6, ACCL_S5, INCL_S6, and INCL_S5). The channel load estimates enable the calculation of loads derived from riparian areas of specific sets of stream reaches, which is typically where gold and silver mine tailings and ore processing mill waste are found. SPARROW's calculation of incremental sediment input to each NHDPlusV2 reach and total sediment yield at any downstream node also provides a direct estimate of the sediment delivery

ratio through the stream network. Steps taken to gather, process, and apply SPARROW model outputs are briefly described in the following subsections.

A-4.1 SPARROW MODEL DATA PROCESSING

The SPARROW topology consists of catchments and reach segments. Each catchment represents the direct drainage to a single reach segment and both are indexed by a common identifier or COMID¹. The ends of each stream segment are identified by “From” and “To” nodes. These nodes show both the direction of flow and the routing linkage between reach segments.

The SPARROW Southwest model contains 444,594 catchments with an average area of 5.2 km² and impairments located on higher-order streams may have many thousands of contributing upstream catchments. To reduce the analysis to a feasible level we spatially aggregated COMIDs up to the HUC12 scale, as described below. On average, a HUC12 contains 25 COMID catchments.

A-4.1.1 Identifying Downstream COMID for Hg-Impaired Waterbodies

We digitized point location coordinates for each of the 31 Hg-impaired waterbodies in ArcGIS Pro editor tool and recorded the most downstream corresponding (a) NHD catchment COMID value and (b) NHD stream reach node value for each digitized location. In cases where an impaired stream segment fell on the edge of two NHD catchments, the waterbody overlap was evaluated. If the overlap into the more downstream NHD catchment was small (i.e., less than 100 feet for stream reaches) we used the more upstream NHD reach. For lakes and reservoirs, we ensured that the selected downstream COMID reach spanned the outlet structure so that it could be used to identify retention within the lake.

A-4.1.2 Identifying Upstream COMIDs Draining to Hg-Impaired Waterbodies

We leveraged (a) the point location coordinates from the previous processing step and (b) information included in the NHD flowline dataset (e.g., “to” node and “from” node identification numbers) to iteratively identify all NHD catchment COMIDs that are upstream of the point location coordinate. More specifically, Python code was used to route connections upstream and gather all upstream NHD catchments, repeating this process for each waterbody. The resulting outputs included: (a) spatial GIS feature layers (one file for each waterbody) with the boundaries of all upstream NHD catchments and (b) a single tabular data file including information for all 31 impaired waterbodies at the downstream NHD catchment COMID and all upstream NHD catchment COMIDs.

A-4.1.3 Relating COMIDs to HUC12 Subwatersheds in Hg-Impaired Watersheds

To efficiently estimate transit losses, delivery factors were calculated and applied at the HUC12 scale for each HUC12 subwatershed that contributes to the impaired waterbody of interest. These delivery factors express the relationship between loads generated within a subject

¹ COMID = stream segment and catchment unique identifier in the SPARROW model and other geospatial frameworks such as StreamCat (Hill et al., 2016). Note that in some NHDPlusV2 files, such as catchment shapefiles, COMID is labeled as ‘FEATUREID’ in attribute tables.

upstream HUC12 and loads reaching a downstream Hg impairment, such as a downstream lake or reservoir. Transit losses are calculated from concatenating SPARROW model output for both flow and sediment along the COMID network of reaches connecting each source area to the impairment. Flow-based losses are then applied to dry atmospheric deposition of Hg direct to water surfaces, wet atmospheric deposition that is carried to waterbodies via surface runoff and point source discharges of Hg. Sediment-based losses are applied to erosion-related sources of Hg containing upland soils and stream/riparian sediments. Both types of losses are calculated at the local level as the ratio of outflow from the HUC12 to the sum of input from upstream HUC12s and incremental input from SPARROW COMID catchments within the HUC12 of interest. The total rate of Hg transmission to a downstream impaired waterbody is then calculated by concatenating the losses incurred from loads originating from each HUC12 area to the downstream waterbody after accounting for losses in each intervening reach segment and then summing the delivered loads from all upstream HUC12 areas. For large reservoirs, this may involve calculation across several hundred source areas that may be intercepted by other, upstream impairments.

For transit loss calculations, a relationship between each impaired WBID of interest, each upstream COMID catchment included in the impaired WBID drainage area, and each HUC12 contributing to the impaired WBID was developed in a series of linkable tables for data processing. These tables were used to develop a network diagram for each impaired waterbody which identifies the HUC12s draining to the impairment, how they are connected, how the SPARROW model’s COMID catchments relate to them, and the associated net transit losses.

A-4.1.4 SPARROW Model Data Gathering

We gathered USGS SPARROW water balance and suspended sediment transport data for NHD catchments in Arizona and used Python code to pull selected water balance and sediment variables for each waterbody (Wise et al., 2019). Select SPARROW attributes are shown in Table A-4-1. To calculate the loading contributions from all upstream COMID catchments for each impaired waterbody, we used Python and Visual Basic for Applications (VBA) code in Excel to sum incremental and net downstream loads to obtain a single representative value for the relationship between each impaired segment and all contributing upstream segments.

Local sediment loads and flows from within the HUC12 that contains the impairment are calculated from the incremental loads from COMIDs upstream of the downstream COMID identified in Section A-4.1.1 and the associated reductions to the downstream point. Net delivered loads and flows from HUC12s upstream of the HUC12 containing the impairment are based on aggregated incremental loads and flows from all the COMIDs within the HUC12, any loads from additional HUC12s further upstream, and estimated transit reductions based on the loads at the HUC12 pour point divided by the incremental source loads. Loads and flows from further upstream are ultimately estimated based on the product of throughput (1 minus the reduction) of all intervening HUC12s:

$$H12_i = \prod_{j=1}^{k_i} (1 - R_j) \times \sum_{l=1}^{m_i} C_l$$

where $H12_i$ is the net delivered load from HUC12 i , k_i is the number of HUC12s on the path from HUC12 i to the impaired waterbody, R_j is the reduction fraction estimated for HUC12 j , m_i is the number of COMIDs within HUC12 i , and C_l is the load or flow from each COMID contained

within HUC12 *i*. Hg transport is then calculated based on the transport of water and sediment as explained in Section A-5.0.

Table A-4-1. SPARROW water balance and suspended sediment variables used in this analysis.

Constituent	SPARROW Attribute	Description
Water Balance	IncAreaKm2	Incremental drainage area (km ²)
	Incusarkm2	Incremental drainage area in the U.S. (km ²)
	CumAreaKm2	Total upstream drainage area (km ²)
	Cumusarkm2	Total upstream drainage area in the U.S. (km ²)
	STRM_NAME	Stream name
	ACCL	Total accumulated streamflow (cfs)
	ACCY	Accumulated water yield (mm/yr)
Suspended Sediment	INCL	Incremental streamflow (cfs)
	Wbm_meanq	Mean annual streamflow (cfs)
	ACCL	Total accumulated load (Mt/yr)
	ACCL_S5	Accumulated load from alluvial sources (Mt/yr)
	ACCL_S6	Accumulated load from channel sources (Mt/yr)
	INCL	Incremental load (Mt/yr)
	INCL_S5	Incremental load from alluvial sources (Mt/yr)
INCL_S6 ^a	Incremental load from channel sources (Mt/yr)	

Note: The INCL_S6 sediment variable is reported incorrectly in the current data release for the Southwest SPARROW model and was apparently overwritten by other data; however, the correct value can be recovered by subtracting the values for INCL_S1 through INCL_S5 from the reported total incremental load (INCL). Further variable description is included in the USGS SPARROW model attribute tables distributed with the SPARROW databases (Wise et al., 2019).

A-5.0 POLLUTANT SOURCE INVENTORY

Pollutant sources fall into two broad classes: point sources and nonpoint sources. The CWA and accompanying regulatory guidance define point sources as discernable, confined, and discrete conveyances, including but not limited to pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operations, or vessel or other floating craft, from which pollutants are or may be discharged (CWA § 502(14)). Some examples of common point sources include discharges from municipal wastewater treatment facilities, mines, industrial operations, and Municipal Separate Storm Sewer Systems (MS4s). A nonpoint source is defined as any source of water pollution that does not meet the legal definition of a point source in the CWA. Nonpoint sources of pollution generally result from land

runoff, precipitation, atmospheric deposition, drainage, seepage, or hydrologic modification. Nonpoint source pollution, unlike point sources, comes from many diffuse sources (USEPA, 2020a).

A-5.1 POINT SOURCES

Point sources are subject to regulation and emission limits and must be addressed in the TMDL. In addition to direct discharges associated with the mining of Hg or the processing of gold and silver ores using Hg amalgamation, other permitted point sources – whether they affect air, surface water, or other media – can significantly contribute to Hg pollution that reaches waterbodies. This can happen when wastewater treatment plants handle substantial Hg content from industrial origins or medical sources like dental amalgam. Additionally, municipal stormwater may carry Hg from places such as automobile junkyards or steel recycling facilities that process Hg switches from vehicles and other devices. The following subsections summarize approximations of point source contributions of Hg to Arizona’s impaired waterbodies.

A-5.1.1 Point Sources to Water

A-5.1.1.1 Monitored Hg Point Source Load

Effluent Hg monitoring is required for facilities where discharge of Hg is a concern to receiving waterbodies. Currently, there are approximately 130 individual Arizona Pollutant Discharge Elimination System (AZPDES) permits issued for point source discharges to Arizona’s protected surface waters. Among individual active AZPDES permits, 21 contain provisions requiring Hg effluent monitoring and are located within the upstream drainage areas of Hg-impaired lakes and streams shown in Figure A-5-1 and summarized in Table A-5-1. However, five of those facilities only reported “NA” entries for Hg monitoring in recent years (2016 to 2023), due to no discharge to statutory surface waters or instances where all analyzed samples were below the detection limit of the analysis method used. Additionally, one facility was issued a permit in January 2024 and did not have Hg monitoring data available prior to that time. Thus, the analysis of Hg contributions from point source dischargers was performed using data from the remaining 15 facilities located within impaired watersheds that reported quantified Hg concentration values in Discharge Monitoring Reports (DMRs). Hg concentration and load data for individual AZPDES permitted discharges was obtained from DMRs submitted to ADEQ by facilities for the years 2016 to 2023. ADEQ previously analyzed Hg DMR data from 2011 to 2022 for a stormwater study carried out by the Permits department, so these load summaries, when available, were used for estimating current point source contributions to impaired waters within the state.

Table A-5-1. List of AZPDES Dischargers Included in the Statewide Hg TMDL Data Analysis.

Facility/Source	Permit Number ^a	Facility Type	Status	Waterbody ID (WBID)	Waterbody Name
USDOI BR-Glen Canyon Dam and Powerplant	AZ0026182	NON-POTW	Minor	AZL14070006-1130	Lake Powell

Facility/Source	Permit Number ^a	Facility Type	Status	Waterbody ID (WBID)	Waterbody Name
Freeport-McMoRan Bagdad Inc.	AZ0022268 ^b	Mine	Major	AZL15030204-0040A	Alamo Lake
Petro Stopping Center WWTP	AZ0022756	NON-POTW	Minor	AZL15030204-0040A	Alamo Lake
Town of Patagonia WWTP	AZ0025011	POTW	Minor	AZL15050301-1050	Patagonia Lake
Patagonia Lake State Park WWTP	AZ0026620 ^c	POTW	Minor		
January Mine Hermosa Project	AZ0026387 ^b	Mine	Major		
Houston Creek Landing WWTP	AZ0025305 ^b	NON-POTW	Minor	AZ15060105-009 AZL15060103-1240 AZL15060106A-0070 AZL15060106A-0250	Tonto Creek Roosevelt Lake Apache Lake Canyon Lake
City of Globe WWTP	AZ0020249	POTW	Major	AZL15060103-1240	Roosevelt Lake Apache Lake Canyon Lake
Pinto Valley Mine	AZ0020401	Mine	Major	AZL15060106A-0070	
Miami Wastewater Reclamation Facility ^d	AZ0025909 ^b	POTW	Minor	AZL15060106A-0250	
American Gulch WWTP	AZ0020117 ^b	POTW	Major	AZL15060203-0110	Bartlett Lake
Sedona Venture WWTP	AZ0021807	NON-POTW	Minor		
Flagstaff Meadows WWTP	AZ0024708	NON-POTW	Minor		
Pinewood Sanitary District WWTP	AZ0025879	NON-POTW	Minor		
Big Park Domestic Wastewater Improvement District WWTP	AZ0024082	NON-POTW	Minor		

Facility/Source	Permit Number ^a	Facility Type	Status	Waterbody ID (WBID)	Waterbody Name
Town of Jerome WWTP	AZ0021804	POTW	Minor	AZL15060203-0110	Bartlett Lake
City of Cottonwood WWTP	AZ0024716	POTW	Major		
Iron King Water Treatment ^e	AZ0024546 ^b	NON-POTW	Major		
Kings Ranch Unit II WWTP	AZ0023060 ^b	NON-POTW	Minor	AZL15070102-1100	Lake Pleasant
Bensch Ranch Estates WWTP ^f	AZ0024813 ^b	NON-POTW	Minor		
Black Canyon Ranch RV Resort WWTP	AZ0024741	NON-POTW	Minor		
Chimney Estates, LCC WWTP	AZ0026999	NON-POTW	Minor		
Town of Prescott Valley WWTP	AZ0025381	POTW	Major		
Softwinds Mobile Home Park WWTP	AZ0026051	NON-POTW	Minor		

- a. AZPDES permit identification number.
- b. AZPDES facilities without Hg data available in DMR reports (i.e., all entries recorded as “NA”), often due to samples being less than the detection limit used for the analyses.
- c. AZPDES permit AZ0026620 became effective in January 2024. At the time of issuance, no Hg monitoring data was available for the facility, so no Hg limits were initially established. However, ADEQ’s Permits Department calculated an average monthly Hg mass limit of 0.0007 g/day and a maximum daily mass limit of 0.0015 g/day. Since this is a newly permitted discharge, it can be treated as an additional load for TMDL calculations. This load is not included in the SPARROW-based load analyses for the Patagonia Lake drainage area, which were calibrated using data collected prior to the activation of AZ0026620.
- d. This permit was terminated in 2021.
- e. This permit was terminated in 2013.
- f. This permit was terminated in 2018.
- g. City of Williams WWTP, permit AZ0025755, discharges to the same HUC12 (150100040502) as impaired Santa Fe Reservoir (WBIDAZL15010004-1340); however, the discharge is downstream of the reservoir and is thus excluded from the Hg loading analysis for Santa Fe Reservoir.

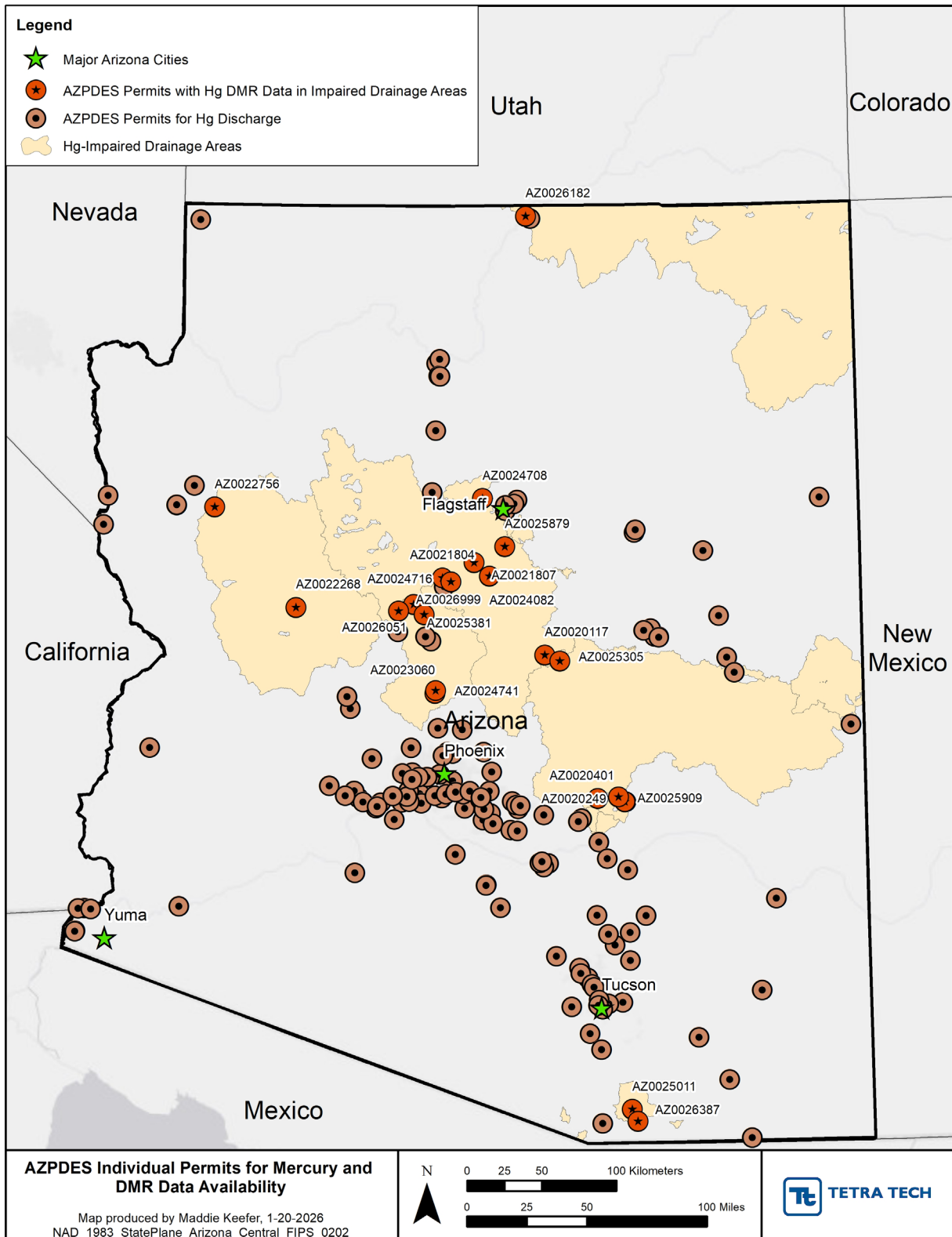


Figure A-5-1. Permitted AZPDES facilities with monitoring requirements for Hg.

A-5.1.1.2 Stormwater Hg Loads

Stormwater from municipal separate storm sewer systems (MS4s) is considered a point source and is subject to AZPDES permits. MS4 stormwater should consist of stormwater and runoff from the contributing watershed.

ADEQ’s GIS team does not produce a static map of the Phase II MS4 boundaries within the state because MS4 jurisdictions are tied to city and town limits in addition to the most recent census. However, overlaying city and town limits with recent urban census coverages (2000, 2010, and 2020) provides a general outline of the majority of the regulated MS4 areas. MS4 boundaries primarily do not overlap the upstream drainage areas of Arizona’s Hg-impaired lakes and streams. Some MS4 areas do exist within the upstream drainage areas of Lake Pleasant (e.g., Prescott, Prescott Valley, Yavapai County, and ADOT MS4s) and Bartlett Lake (e.g., Sedona, Cottonwood, Camp Verde, Yavapai County, Coconino County, ADOT MS4s), but those overlapping areas are quite small compared to the overall surface area of the watershed (approximately less than 5-10%).

Since a significant portion of Hg in stormwater is believed to originate from atmospheric deposition (e.g., Minnesota Pollution Control Agency, 2007), the exact contribution of stormwater to overall Hg loading remains uncertain. Consequently, Hg reductions in stormwater for the statewide TMDL will be addressed through initiatives targeting reductions in atmospheric deposition.

A-5.1.1.3 Ongoing Mining Operations

Historic mining operations in Arizona for Hg, gold, and silver in the 19th and early 20th centuries were an important source of environmental releases of Hg, both as a direct by-product of mining and through the use of the Hg amalgamation process to concentrate gold and silver from ore. These operations took place mostly prior to the Clean Water Act and the institution of discharge permits, so most Hg derived from historic mining sources is treated as a nonpoint source (Section A-5.2.3).

Arizona is currently the top producer of copper in the United States. According to the Arizona Geological Survey’s (AZGS) Open-File Report 22-06, titled "Directory of Active Mines in Arizona: FY2022," there are 441 active, full-time mines or development projects in the state, as detailed in Table A-5-2 (Garcia et al. 2022). However, only 29 of these are active metal mines, with 17 focused on copper and 11 producing gold and/or silver. A separate spatial dataset, ‘mineplant-fUS04.shp’, available from the USGS, covers only 171 active mines, including 14 copper and 5 gold and/or silver mines, but this dataset is limited to mines recorded by the National Minerals Information Center as of 2003 (USGS, 2005). Neither dataset accounts for ongoing artisanal or small-scale hobby mining operations.

Table A-5-2. Active Mines in Arizona, 2022.

Commodity Family	Count
Aggregates and Crushed Stone	301
Cinders	18
Metals	29

Commodity Family	Count
Cement and Lime	5
Other Industrial Minerals	5
Building Stone	68
Uranium	2
Smelter	3
Gemstones	5
Gypsum	4
Training Mine	1

There are three active metal mining operations (primarily copper mines) within the study areas of interest for the statewide TMDL analysis that affect Hg impaired waterbodies and have discharge limitations and monitoring requirements for Hg as a byproduct of their operations. These permits are included in the DMR dataset Hg load estimation in this TMDL. These mining operations all maintain individual AZPDES permit coverage and available quantified discharge monitoring results for Hg loading were included in the analysis of point source discharges to impaired waters. The active mining permits within the study areas of interest that must monitor Hg concentrations in discharge include:

- Freeport-McMoRan Bagdad Inc. (AZ0022268) — HUC 150302030307
- January Mine Hermosa Project (AZ0026387) — HUC 150503010203
- Pinto Valley Mine (AZ0020401) — HUC 150601030703

Note that in this context, the USGS Hydrologic Unit Code (HUC) is defined as the watershed to which the permit outfalls discharge. Asarco, LLC, Asarco Ray Operations (AZ0000035) discharges to Mineral Creek in HUC 150501000207 and has monitoring requirements for Hg. Portions of Mineral Creek within this HUC are impaired for Hg; however, the Hg impaired segment is upstream of the permitted discharge from the Ray Mine.

A-5.1.2 Air Permits

The Toxics Release Inventory (TRI; <https://www.epa.gov/toxics-release-inventory-tri-program>) was queried to see if there were any database records in Arizona for Hg air emissions to water. Only one facility was returned for current TRI records: Freeport-McMoRan Miami Inc. (TRI Facility ID 85532NSPRTPOBOX), a copper mining company located in Claypool, AZ in Gila County. According to the TRI, this facility has emissions of Hg to water of approximately one lb/yr. This facility also has an individual AZPDES permit, AZ0024350, and AZPDES De Minimis General Permits (DMGP; AZD020508, AZD002050). De Minimis discharges are considered to make negligible contributions to Hg loading (ADEQ, 2021). Likewise, ADEQ does not currently have Hg monitoring data for the AZ0024350 permit. As such, Hg discharge from this facility was not included in calculated estimates of existing Hg loads to protected surface waters in Arizona.

A-5.2 NONPOINT SOURCES

The following subsections summarize estimates of Hg loads by pathway with emphasis on the total load at the outlet of each Hg-impaired waterbody segment.

A-5.2.1 Atmospheric Deposition

Hg circulates globally in the atmosphere, primarily in elemental and ionic forms. Much of the atmospheric Hg load was derived from coal burning; however, the oceans contain a substantial mass of elemental Hg that equilibrates with the atmosphere so that the atmospheric concentration responds only slowly to reductions in emissions. Deposition of atmospheric Hg is an important and ongoing load source to watersheds and waterbodies worldwide. This atmospheric deposition can occur as wet deposition, associated with precipitation, and dry deposition that occurs in the absence of precipitation. The wet deposition pathway consists primarily of ionic Hg that is dissolved into water droplets in the atmosphere and is relatively easy to measure in rainfall samples. Dry deposition is a more complex and more difficult to measure process that includes bi-directional transport between the atmosphere and land or water surfaces. Dry deposition includes ionic Hg that is associated with fine particulate matter such as smoke or aeolian dust, both of which may also be incorporated into wet deposition; however, a major pathway for dry deposition is the uptake of elemental Hg by plant leaves, much of which is eventually converted into ionic forms and incorporated into soil via leaf litterfall.

A-5.2.1.1 Atmospheric Hg Deposition Rate Estimates

Some past Hg TMDLs for impaired Arizona lakes used estimates of atmospheric deposition of Hg from the Regional Modeling System for Aerosols and Deposition (REMSAD) system. More detailed and more recent summaries of Hg deposition are now available from the Western North American Hg (WNAM) project (Domagalski et al., 2016). The deposition grids (800 m resolution) developed by the WNAM project provide annual total Hg wet deposition estimates in $\mu\text{g}/\text{m}^2$ for the period 2000 to 2013. The WNAM project gridded dataset was developed from monitoring data collected by the National Atmospheric Deposition Program Hg Deposition Network (NADP-MDN; <http://nadp.sws.uiuc.edu/mdn>) coupled with estimates of dry deposition at a resolution of 40 km. The MDN point estimates of total Hg concentration were converted to loads and interpolated based on gridded precipitation data from PRISM (Parameter-elevation Relationships on Independent Slopes Model; <http://prism.oregonstate.edu>). Atmospheric deposition fluxes were estimated across the watershed and summarized for each land use/cover in the drainage area. The Arizona statewide TMDL analysis uses the WNAM results for wet deposition because they are based on measured data, cover a longer time period than REMSAD, and are available at a finer spatial scale.

Wet deposition fluxes from the WNAM project were extracted for the watersheds of interest and applied for load estimation purposes. Figure A-5-2 displays the resulting average annual WNAM wet Hg deposition grids for the state of Arizona. Estimated loading rates of Hg wet deposition grouped by Arizona land use are shown in Table A-5-3. For a site-specific example, Figure A-5-3 displays the average annual WNAM wet Hg deposition grids for the Lake Pleasant (WBID AZL15070102-1100) drainage area. The annual average load of Hg in wet deposition to the Lake Pleasant drainage area is 22,876 g/yr, only a fraction of which is delivered to the lake network. After accounting for losses during transit to the lake surface, the estimate of wet atmospheric deposition of Hg delivered to Lake Pleasant via overland runoff is approximately 1,257 g/yr.

Table A-5-3. Estimated atmospheric Hg wet deposition (mean rate and total) by land use categories.

Land Use Category	Mean Atm. Wet Dep. Rate (µg/m ² /yr)	Total Wet Deposition (kg/yr)
Rangeland	4.0	832.3
Forest	7.4	280.1
Grassland/Herbaceous	4.4	124
Developed	3.6	27.6
Barren Land	2.2	17.1
Agricultural Land	2.5	12.1
Wetlands	3.4	4.9
Open Water	3.2	1.7
Statewide Total	-	1,299.8

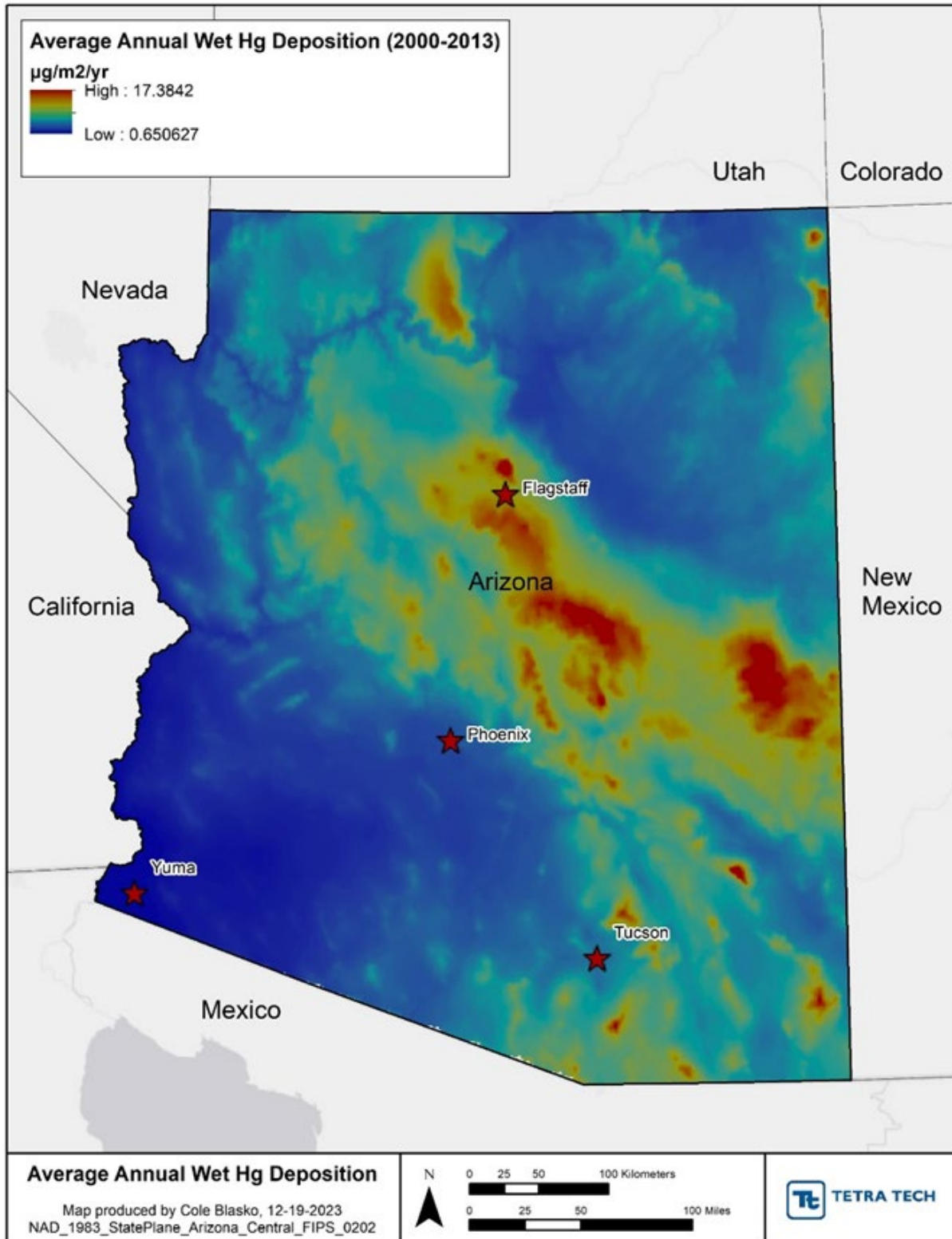


Figure A-5-2. Average annual Hg wet deposition for Arizona, 2000-2013.

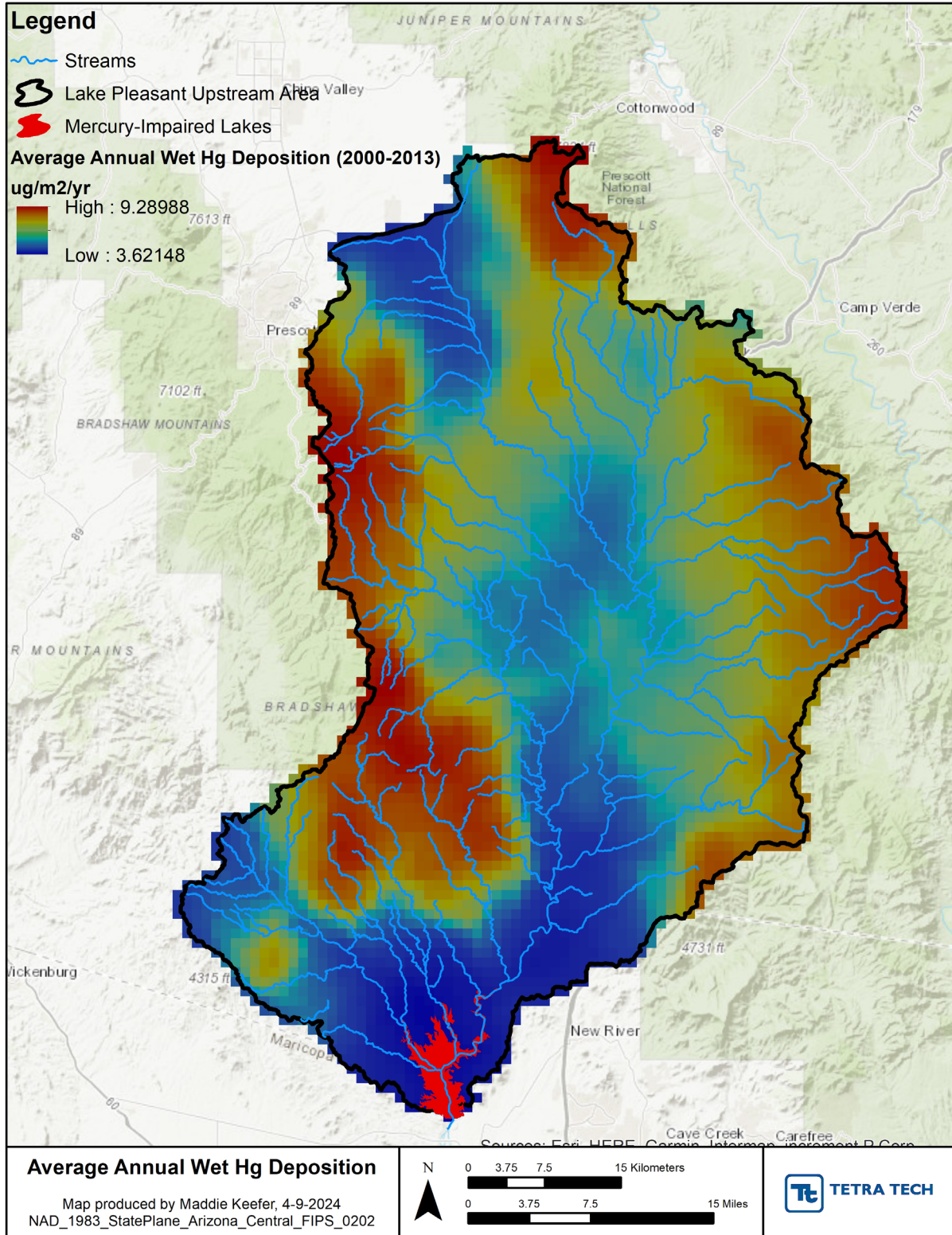


Figure A-5-3. Average annual Hg wet deposition for Lake Pleasant (AZL15070102-1100), 2000-2013.

It is difficult to directly measure net dry deposition because there are complex bi-directional atmospheric fluxes and much of the deposited Hg is re-emitted to the atmosphere. Dry deposition fluxes provided by Domagalski et al. (2016) are estimated from the Community Multiscale Air Quality (CMAQ; <https://www.cmascenter.org/cmaq/>) model run for 2009 conditions at a 40-km spatial resolution. The 2009 results are assumed to approximate dry deposition rates for other years as well and range from 3.40 to 16.21 $\mu\text{g}/\text{m}^2/\text{yr}$. Bullock et al. (2008, 2009) demonstrated that REMSAD and CMAQ have similar levels of skill in predicting wet atmospheric deposition of Hg, but CMAQ (in the configuration used by Bullock et al.) predicted substantially higher dry deposition rates. The 2009 dry atmospheric deposition flux for the state is approximated as 1,739 kg/yr. As with wet deposition, only a small fraction of this Hg is delivered to the network of lakes, reservoirs, and streams.

Dry deposition of Hg is enhanced by leaf uptake and subsequent litter fall in areas with vegetation. For the TMDL mass balance, loads to the stream network from dry deposition of Hg to upland land surfaces are represented implicitly via soil concentrations that reflect the net deposition and re-emission of Hg.

Dry deposition loads of Hg are also estimated separately for direct deposition to waterbody surfaces for the TMDL. Gridded annual total Hg dry deposition ($\mu\text{g}/\text{m}^2/\text{yr}$) data were calculated over Arizona's Hg-impaired watersheds for major lakes, streams, and areas classified as Open Water land use in the National Land Cover Data set (NLCD) 2021. Zonal Statistics was used to calculate an estimated total dry Hg deposition load on waterbody surfaces, prior to accounting for losses during transit, within Arizona's impaired watersheds as approximately 5,426 g/yr. For a site-specific example, the estimate of dry Hg deposition for the Lake Pleasant (AZL15070102-1100) drainage area, after accounting for transit losses, is 242.41 g/yr.

A-5.2.1.2 Delivery Ratio Estimates for Hg Wet Deposition

Precipitation falling on the watershed infiltrates into the ground, returns to the atmosphere via evapotranspiration, or runs off into streams. As a first approximation, only the fraction of wet deposition of Hg associated with precipitation that becomes runoff is available to be transported to the stream network. The United States Geological Survey (USGS) water-balance model (WBM) (Wieczorek et al., 2024, which is also the basis for the flows simulated in SPARROW) is used to calculate this fraction—referred to as the runoff ratio. The estimate of Hg load in g/yr associated with the direct surface runoff of wet atmospheric deposition is obtained by multiplying the average annual wet deposition rate from the gridded WNAM analysis by the fraction of precipitation that becomes runoff from the WBM.

We first assume that the spatial pattern of wet deposition of Hg (Figure A-5-2) and the spatial pattern of runoff generation are good indicators of the spatial pattern (although not the total mass) of dissolved Hg delivered to the stream network. For this analysis, the wet deposition Hg load was first updated with estimates of the fraction of precipitation converted to runoff for each Hg-impaired upstream drainage area from the gridded WBM, which reflects the land use categories in the watersheds. Spatially varying runoff-to-precipitation (mm/mm) ratios were calculated using extracted annual average runoff and precipitation estimates from the WBM. As an example, Figure A-5-4 shows the spatially varying runoff ratios across the Lake Pleasant upstream drainage area.

The runoff estimated by the WBM includes both direct overland flow and shallow subsurface soil flow pathways. Hg transmitted through the soil will likely experience variable rates of attenuation due to sorption or re-volatilization that vary with residence time and reduce the total load. The WBM and Southwest SPARROW also account for flow via deeper groundwater pathways the

returns to surface waterbodies via springs. However, these are not simulated as significant contributors to flow in any of the reach networks upstream of the impaired WBIDs.

Most of the Hg load derived from atmospheric deposition is not delivered directly to streams but rather is retained in the landscape. Domagalski et al. (2016) summarize ratios of Hg yield in streams relative to total Hg deposition (wet plus dry) for the western US and state that in non-Arctic regions watersheds with natural vegetation tended to have low ratios of Hg runoff (mostly < 10%) whereas urbanized watersheds had higher ratios (34 – 100%) because of runoff from impervious surfaces.

The delivery ratios presented by Domagalski et al. (2016) relate stream Hg yield to the sum of wet and dry atmospheric deposition in the watersheds of interest. Delivery of Hg sorbed to eroded soil, assumed to be largely derived from current and historic dry atmospheric deposition, is analyzed independently based on soil erosion analysis (Section A-5.2.2).

The runoff ratio accounts for the fraction of wet deposition load that contributes to the stream network. Further losses may occur in transit between an upstream HUC12 and an impaired WBID. While various processes contribute to these losses, the most significant in an arid climate is due to diversion of water for consumptive use. This is accounted for by calculating the ratio between water entering a HUC12 and water present at the outlet of the HUC12 and treating this as the fraction of wet deposition load that is transmitted through the HUC12. For contributing HUC12s that are far upstream of a WBID of interest, the total fraction of wet atmospheric deposition reaching the downstream WBID must be calculated as the product of the transmission factors for all intervening HUC12s. An estimate of the net effect of other processes that deplete the wet atmospheric deposition load can be approximated by adjusting the predicted concentration in the downstream WBID to approximate available monitoring data.

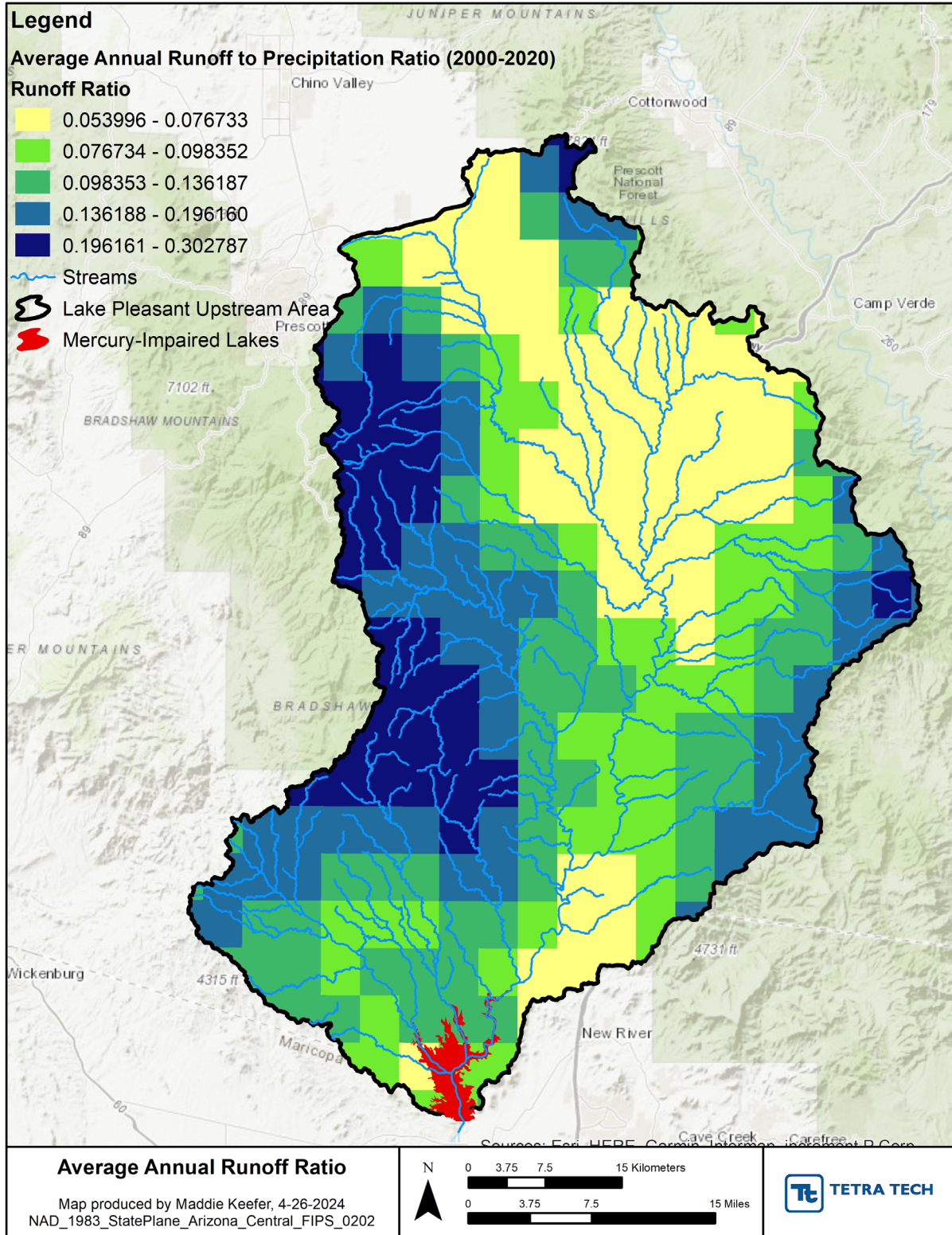


Figure A-5-4. Lake Pleasant (AZL15070102-1100) runoff-to-precipitation ratios from the USGS WBM.

A-5.2.2 Geological Background Erosion

Hg is present in upland soils, largely in ionic form, due to natural geology combined with decades of atmospheric deposition. Erosion of upland soils can bring this Hg into the stream network. We estimated these loads by combining SPARROW estimates of upland sediment erosion delivered to the stream network with estimates of surface soil (top 5 cm) THg concentrations.

5.2.2.1 Hg Concentrations in Soils

Hg concentrations in surface soils are expected to vary by geology, soil properties, and land use due to the varying retention and re-emission rates associated with different land use/cover types (Eckley et al., 2016). For example, dry deposition of Hg to soil is largely controlled by the amount of leaf litter accumulation. USGS (Smith et al. 2019) developed a gridded map of soil Hg concentrations throughout the conterminous US based on relatively sparse surface soil (top 5 cm) samples, with inverse distance weighting between measured points. Because of the sparse distribution of soil Hg concentration samples within Arizona, it was not feasible to refine estimates based on land cover type, but there was a need to account for the variation of geology across the state. To do this, we split Arizona into areas with and without igneous and hydrothermal geology and recalculated the inverse distance weighted interpolation (following the methods in Smith et al. (2019)) of soil Hg concentrations for those two sectors separately. Rather than using the highly detailed spatial coverage of geology types for Arizona, we classified these areas by HUC12 subwatershed in a more general way using the mining index (MI) which is described in Section A-5.2.3. Based on the analysis of MI estimates compared to concentrations of THg on solids, it appeared that a cutoff of local HUC12 MI values greater than 0.005 was appropriate to identify the geologic areas likely to have higher natural background soil Hg concentrations. After the geologic segmentation and recalculation of the inverse distance weighted soil concentration grids, the resulting average and median soil Hg concentrations for HUC12s with local MI values greater than 0.005 are 36.6 µg/kg of soil and 22.1 µg/kg of soil, respectively. The average and median representative soil Hg concentrations for HUC12s with local MI values below the cutoff of 0.005 are 19.4 µg/kg of soil and 18.0 µg/kg, respectively. When calculating Hg loads to impaired waterbodies from upland areas, the average soil Hg concentrations, assigned to each upstream HUC12 based on mining index values, were applied.

A-5.2.2.2 Sediment Yield Estimation from Upland Areas

As previously mentioned, we estimated the Hg loads attributed to geologic background erosion from upland areas by combining SPARROW estimates of upland sediment erosion with estimates of surface soil THg concentrations and downstream transport rates. The SPARROW model provides total accumulated sediment load (average Mt/yr) at each stream node (ACCL) as well as incremental load delivered to each segment from the local catchment (INCL), and the sediment load attributed specifically to upland erosion was calculated as the difference between total accumulated sediment load (ACCL) and the sum of channel (ACCL_S6) and floodplain/riparian (ACCL_S5) sediment loads. With Lake Pleasant (AZL15070102-1100) as an example, using SPARROW estimates of sediment delivery via geologic background erosion from upland areas produced an annual average (net) sediment delivery of approximately 41,598 metric tons/year after accounting for transit losses. Combining HUC12-specific estimates of delivered sediment load with average representative soil Hg concentrations for each

subwatershed that contributes to Lake Pleasant suggests an estimated annual contribution of Hg from native soils is approximately 1,082 g/yr for the Lake Pleasant drainage area.

A-5.2.3 Stream Sediment and Floodplain Sources

Historically, Arizona's economy heavily depended on mining for metals like gold, silver, and copper, with gold extraction beginning in the mid-19th century. The primary method for extracting gold and silver involved the Hg amalgamation process, which was a significant source of Hg pollution. During this process, elemental Hg was mixed with crushed ore to bind the gold or silver, and then the Hg was separated by heating the amalgam, which released Hg vapor into the environment. While some Hg was recovered through condensation, much of it escaped into the atmosphere or remained in mine tailings, contributing to localized Hg contamination. The large-scale use of Hg in these operations, which persisted until the 1960s, particularly in small-scale and informal mining setups, resulted in substantial Hg deposition in surrounding ecosystems (Esdaile & Chalker, 2018). These Hg deposits remain environmental concerns due to their potential for mobilization into water bodies.

Most precious metal mines in Arizona, especially those active before 1900, employed this method, and although mining shifted towards cyanidation after the 1880s, Hg use continued in some operations well into the 20th century. Hg contamination was not only linked to its direct use in processing but also occurred naturally in mineral-rich zones. The cinnabar mineral, a Hg sulfide ore, was also mined in Arizona, primarily in the early 20th century. Cinnabar is relatively inert, but elemental Hg is far more reactive and prone to environmental dispersion, particularly in mining areas where atmospheric emissions and surface water runoff could carry Hg to distant ecosystems.

Mining activities, particularly gold and silver operations, generated large volumes of tailings — ground rock residue left after precious metals were extracted. These tailings, often disposed of nearby, may still contain Hg, especially in its elemental form, which was notoriously difficult to contain. These tailings contribute to ongoing environmental Hg issues, especially in areas with significant rainfall or erosion, as Hg in tailings can leach into water bodies or be transformed into bioavailable forms like MeHg, posing risks to aquatic life and humans (Alpers et al., 2005).

While the history of mining in Arizona is well documented, the specific locations of Hg processing sites are less well known, complicating efforts to quantify and address Hg contamination at a site-specific level. From a statewide perspective, the most comprehensive resource for historical mines is the USGS Mineral Resources Data System (MRDS; USGS, 2005). MRDS was created to catalog information on metallic and nonmetallic mineral resources throughout the world and is no longer regularly maintained, but incorporates the available information on historic mine operations, prospects, and claims throughout the U.S. MRDS for Arizona has 12,951 records and includes information on whether a prospect or mine is known to have actually produced metals and the top three commodities that were produced. We subset the Arizona MRDS to select mines that are listed as “Producer” or “Past Producer” and where the list of commodities included gold, silver, or Hg, leaving 4,236 sites. These are the sites where Hg was most likely to have been either directly mined or used in the refining of gold and silver ore and omits the many failed or unworked mineral prospects. These mine sites are shown in Figure A-5-5, with the majority of the sites falling along a diagonal from Mohave Co. in the northwest to Santa Cruz and Cochise counties in the southeast. Of these sites, 48 are identified as Hg producers (Figure A-5-6).

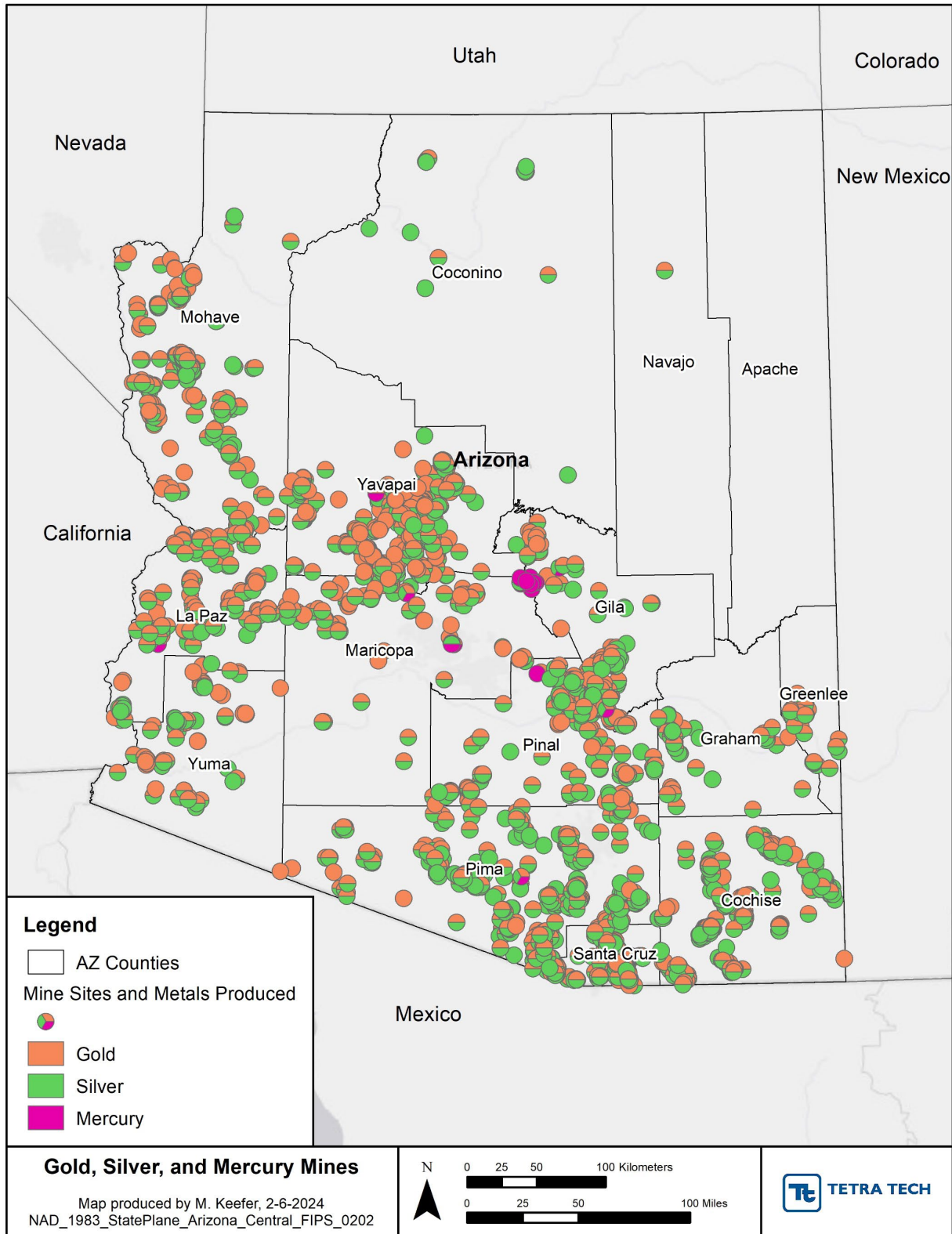


Figure A-5-5. MRDS Records of Mines that Produced Gold, Silver, or Hg in Arizona.

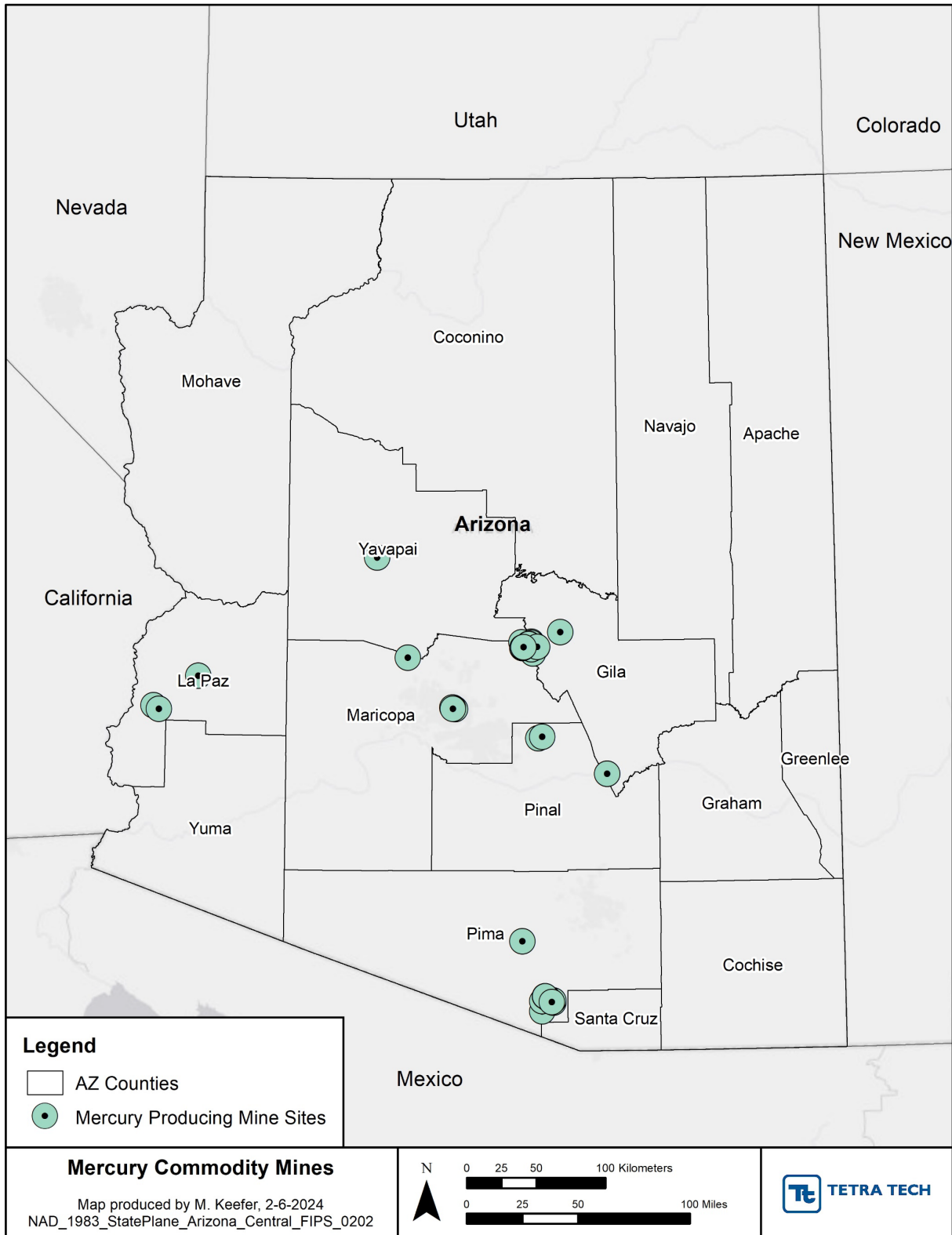


Figure A-5-6. MRDS Records of Historic Mines that Produced Hg in Arizona.

We assume that Hg sources associated with historic gold and silver mining operations (e.g., via Hg amalgamation) will tend to be concentrated near streams due to the need for water in ore processing and its use for powering stamp mills to crush ore. Other anthropogenic sources of Hg, such as abandoned waste sites, are also likely to be in low-lying areas across the state. We used the SPARROW predictions of sediment generated from stream channels and riparian areas to address near-channel sources of Hg loading.

The SPARROW model output provides a way to quantify Hg load associated with the erosion of sediment from main channel and floodplain/riparian sources, as SPARROW estimates the incremental and accumulated average annual flow and sediment load for NHDPlusV2 stream segments and identifies the portion of the load that is attributed to channel or riparian zone erosion.

The SPARROW sediment load from channel and riparian erosion is multiplied by a THg potency factor (ng THg/mg TSS) to estimate THg loads from this pathway. Because sediment and Hg loads from near-channel sources are likely to be much larger than the load from upland erosion except during extreme storm events, the sediment potency was assumed to be approximately equal to the average ratio of sediment-sorbed THg to TSS in stream samples. The potency factors were calculated for samples where both THg and TSS data were available and the THg concentrations were obtained using modern high-resolution analytical detection limits that can report Hg at concentrations of 5 ng/L or less. When possible, sediment-sorbed THg was calculated by subtracting dissolved THg concentrations from the total Hg in water concentrations. Many samples, however, do not report dissolved THg; for these samples, we used total concentrations because the dissolved fraction is usually a small portion of the total Hg concentration at Hg-impaired sites. The potency factors were grouped and summarized by HUC12 watershed.

A THg potency factor can be estimated from samples at a given impaired site; however, we also investigated more generalized methods that could be applied where site-specific sampling was sparse, focusing on THg that may be elevated at or near historic mining operations.

Records on Hg usage for ore processing or the locations of ore mills and retorts (furnaces used to burn off the Hg leaving the associated gold and/or silver) are not available. To approximate the potential for Hg contamination by historic mining activities we calculated a mining index for each HUC12 that is equal to the number of mines documented as producing gold, silver, or Hg divided by the total area. These results were then combined to estimate a cumulative mining index for the entire area upstream of each individual HUC12. The mining index gives only a rough approximation of the risk of mining-related Hg contamination because information on the amount of production of precious metals or the amount of Hg used in processing at individual mines is not available.

The initial application of this approach to the entire Hg monitoring dataset showed a weak negative correlation between sediment potency and the mining index. One contributor to the lack of correlation was the quality of the historic Hg monitoring data, which included many samples with high reporting limits (see Addendum A of this document).

After eliminating samples with inappropriate analytical methods and samples with non-detects, the dataset was reduced to 379 samples from 52 different HUC12 groupings. Of the total 52 HUC12s, 21 HUC12s have a cumulative upstream mine index of zero. Median THg potency versus cumulative upstream mine index does not show a strong relationship (Figure 4-4). First, sites with a cumulative mine index of zero cover most of the range seen with non-zero mine indices. Second, the HUC12 with the highest mine index (150701020506; Humbug Creek in the

Lake Pleasant watershed) also has the lowest calculated THg sediment potency (although the results for this HUC12 are suspect because they are derived from a single usable sample). Nonetheless, there is a positive, although weak correlation ($r = 0.13$) of median sediment potency to cumulative mine index across all available data (Figure A-5-7). There is a negative correlation between the local mine index for a HUC12 and the median sediment potency.

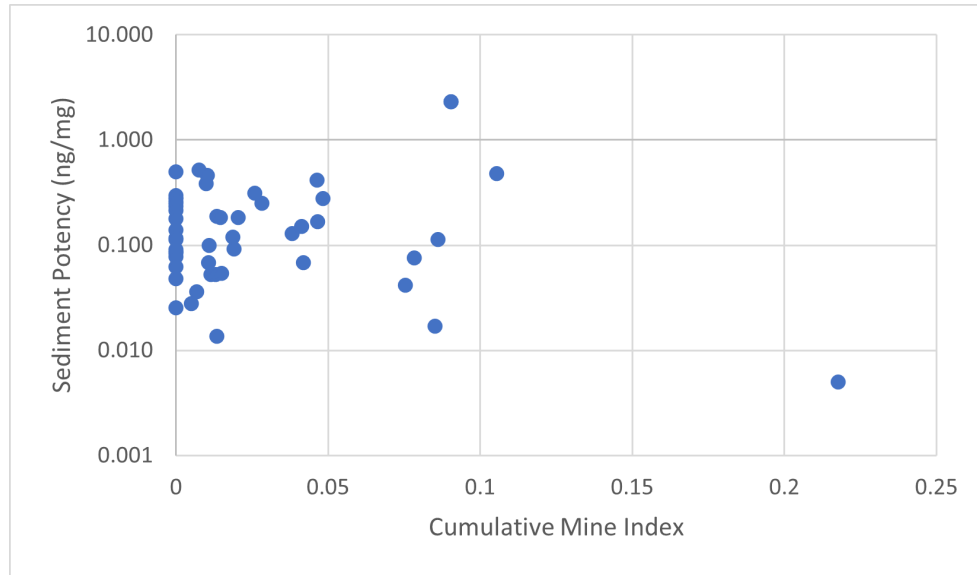


Figure A-5-7. Median THg Potency by HUC12 vs. Cumulative Upstream Mine Index.

Plotting the individual THg potency estimates versus the cumulative mine index shows that the relationship is weak, with little explanatory power (Figure A-5-8). The plot also shows that there can be a wide range of sediment potencies across a single HUC12, which corresponds to an individual mine index, and that sediment potency estimates can be quite high even when there is no documentation of mining in a drainage area.

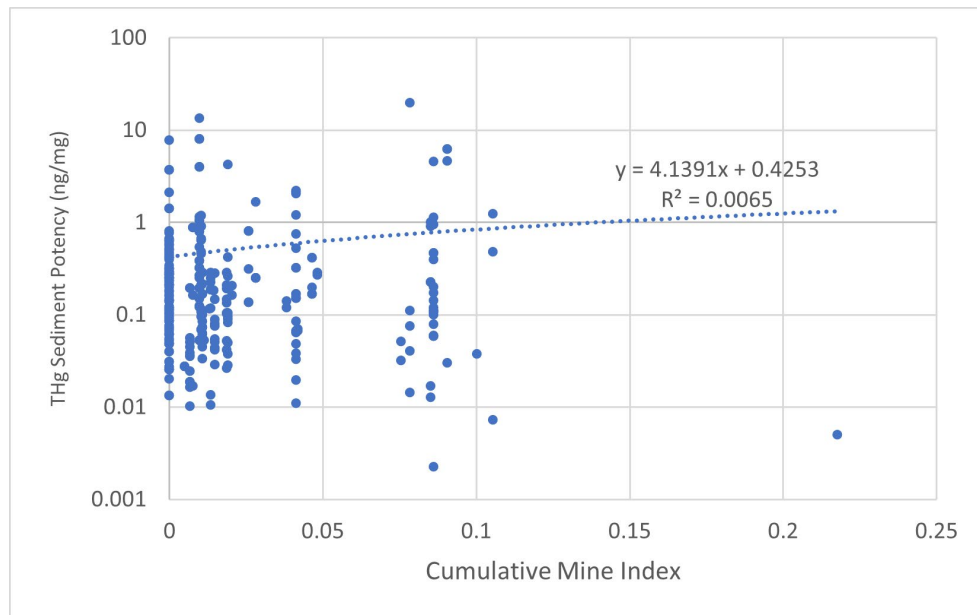


Figure A-5-8. Individual THg Potency Measurements vs. Cumulative Mine Index.

Several data issues likely contribute to the lack of strong correlation. One concern is the grouping of samples by HUC12, which may combine sample locations that are downstream of mines with others that are not. Samples collected during baseflow conditions may not incorporate input from channel erosion. Another concern is that the full set of usable data combines samples from lakes and reservoirs with those from streams. The potency factor approach as an indicator of erosion of mine-contaminated bank and bed sediment is most likely to be applicable to flowing streams. Examining results for only streams (Figure A-5-9) does yield a stronger correlation ($r = 0.0262$), although the explanatory power is still weak (i.e., only 2.6% of the variance in the data is explained by the linear model shown in Figure A-5-9).

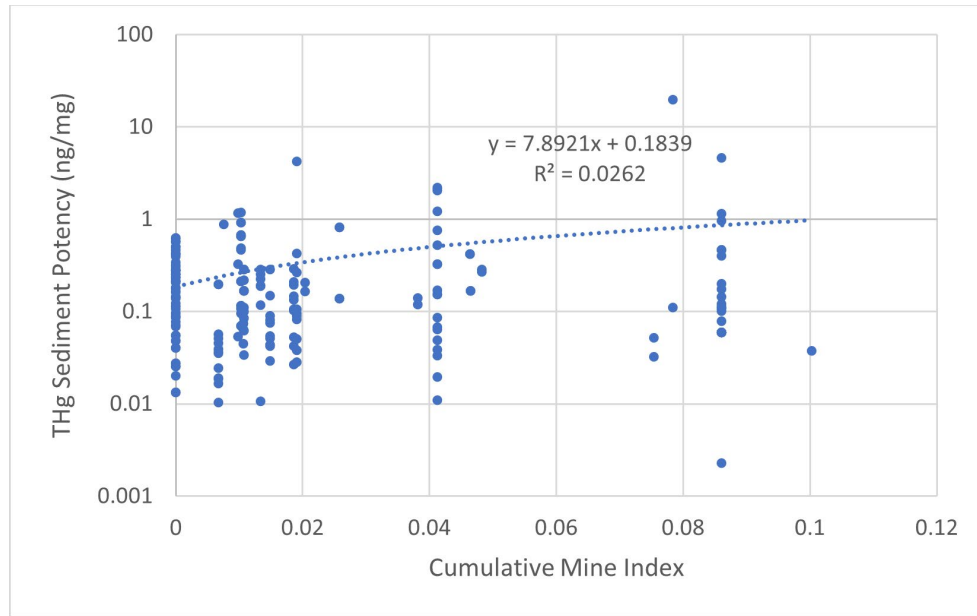


Figure A-5-9. Individual THg Potency Measurements vs. Cumulative Mine Index; Stream Samples Only.

Historic mining has likely contributed to the Hg burden in some waterbodies; however, based on these analyses, the mining index does not provide a tool for general predictions of Hg potency on eroding channel sediment. While a predictive relationship between mining index and sediment THg potency was not found, there is a breakpoint for average sediment potency in streams around a cumulative upstream mining index of 0.03 (Figure A-5-7 to Figure A-5-9). Observations within HUC12 subwatersheds below this mining index level have sediment potency values distributed similarly to areas without mines, while observations in HUC12s with mining index values above 0.03 tend to have slightly higher values. This suggests that areas with low mining indices are likely to not have significant impacts on stream Hg sediment THg potency levels due to past mining and ore processing operations, while those with mining indices above 0.03 have somewhat higher sediment potency levels. Thus, the following average sediment potency values in Table A-5-4 are applied for near-channel erosion relative to the HUC12-level cumulative upstream mining index.

Table A-5-4. THg potency factors to apply in watersheds without site-specific monitoring data.

Mining Index	Average THg Potency (ng THg/mg TSS)
0	0.209
>0 to 0.03	0.248
>0.03	0.734

HUC12-specific estimates of delivered sediment load from channel and riparian sources were combined with sediment potency (ng THg/mg TSS) values, using site-specific data where possible and gap-filling with the default potency factors shared in Table A-5-4 where necessary. Using Lake Pleasant as an example, the total delivered Hg load to the impairment from channel and floodplain sources within its drainage area is estimated to be approximately 1,765 g/yr.

A-6.0 ESTIMATED EXISTING DELIVERED POLLUTANT LOADS

Estimates of point source and nonpoint source loads of THg described in Sections A-5.1 and A-5.2 are combined with the SPARROW-based estimates of delivery through the stream network to estimate the total THg load delivered to each impaired segment. The resulting delivered mass loading estimates by WBID are shown in Table A-6-1. Note that many of the contributing watersheds associated with an impaired WBID are nested (i.e., Canyon Lake is downstream of Apache Lake which is downstream of Roosevelt Lake) so it is not appropriate to sum columns in Table A-6-1, although the estimate of loading to Canyon Lake does account for losses that occur within the upstream lakes. Percentage contributions by source type are summarized in Table A-6-2. These vary widely by WBID but for many of the impaired waterbodies wet atmospheric deposition is a major contributor with a median across all sites of 50 percent.

Table A-6-1. Average annual total Hg loads delivered to each impaired WBID^a.

WBID	Geologic background load (g/yr)	Near-channel load (g/yr)	Wet atmospheric deposition (g/yr)	Dry atmospheric deposition to water (g/yr)	Point source load (g/yr)	Total load (g/yr)
Peña Blanca Lake (AZL15050301-1070)	0.3	<0.1	8.1	1.9	0.0	10.3
Parker Canyon Lake (AZL15050301-1040)	<0.1	<0.1	8.2	5.5	0.0	13.7

WBID	Geologic background load (g/yr)	Near-channel load (g/yr)	Wet atmospheric deposition (g/yr)	Dry atmospheric deposition to water (g/yr)	Point source load (g/yr)	Total load (g/yr)
Patagonia Lake (AZL15050301-1050)	412.1	262.3	218.3	19.6	22.5	934.7
Arivaca Lake (AZL15050304-0080)	<0.1	<0.1	10.3	4.5	0.0	14.8
Scott Reservoir (AZL15020005-1360)	19.8	16.9	130.7	3.4	0.0	170.8
Canyon Lake (AZL15060106A-0250)	3,589.0	5,351.1	18,743.1	900.5	<0.1	28,583.8
Apache Lake (AZL15060106A-0070)	4,574.5	6,353.3	18,643.5	878.9	<0.1	30,450.2
Bartlett Lake (AZL15060203-0110)	3,126.1	5,408.6	10,337.6	356.1	89.8	19,318.2
Lake Pleasant (AZL15070102-1100)	1,081.7	3,137.8	1,656.7	256.5	320.9	6,453.5
Becker Lake ^b (AZL15020001-0150)	9.4	8.8	1.7	0.2	0.0	20.1
Horsethief Lake ^b (AZL15070102-0630)	5.7	0.0	1.0	1.1	0.0	7.8
Willow Springs Lake (AZL15020010-1670)	1.6	0.0	50.5	9.3	0.0	61.4
Black Canyon Lake (AZL15020010-0180)	2.7	0.0	22.4	1.8	0.0	26.9
Alamo Lake (AZL15030204-0040A)	3,397.6	4,537.7	3,297.8	270.7	0.4	11,504.3
Lyman Reservoir (AZL15020001-0850)	4,114.3	1,984.8	909.0	62.4	0.0	7,070.5

WBID	Geologic background load (g/yr)	Near-channel load (g/yr)	Wet atmospheric deposition (g/yr)	Dry atmospheric deposition to water (g/yr)	Point source load (g/yr)	Total load (g/yr)
Soldiers Annex Lake (AZL15020008-1430)	95.6	14.7	32.3	15.4	0.0	157.9
Soldiers Lake (AZL15020008-1440)	92.0	<0.1	32.3	15.4	0.0	139.7
Long Lake (Lower) (AZL15020008-0820)	98.9	18.0	32.3	15.4	0.0	164.7
Lake Mary (Upper) (AZL15020015-0900)	19.2	35.9	281.9	27.6	0.0	364.6
Lake Mary (Lower) (AZL15020015-0890)	89.7	72.7	397.0	52.1	0.0	611.4
Santa Fe Reservoir ^b (AZL15010004-1340)	0.2	0.0	3.9	2.6	0.0	6.8
Roosevelt Lake (AZL15060103-1240)	7,404.8	9,495.9	18,778.8	824.6	<0.1	36,504.1
Devils Canyon (AZ15050100-1662)	2.8	65.0	113.8	4.2	0.0	185.8
Mineral Creek (AZ15050100-012B)	12.1	448.2	259.2	8.7	0.0	751.0
Tonto Creek (AZ15060105-009)	677.4	1,605.8	2,531.3	34.7	0.0	4,849.1
Tonto Creek (AZ15060105-004)	697.2	2,119.1	2,961.1	138.6	0.0	5,916.0
Tonto Creek (AZ15060105-006)	703.2	1,975.6	2,791.6	52.4	0.0	5,522.8
Tonto Creek (AZ15060105-013B)	242.4	609.1	758.5	9.2	0.0	1,619.2
Tonto Creek (AZ15060105-011)	400.9	1,216.7	1,610.6	18.8	0.0	3,246.9

WBID	Geologic background load (g/yr)	Near-channel load (g/yr)	Wet atmospheric deposition (g/yr)	Dry atmospheric deposition to water (g/yr)	Point source load (g/yr)	Total load (g/yr)
Tonto Creek (AZ15060105-008)	740.2	1,894.0	2,500.3	46.4	0.0	5,181.0

- a. Results are calculated at the HUC12 scale.
- b. Becker Lake, Horsethief Lake, and Santa Fe Reservoir results are adjusted to account for drainage areas containing fractions of a HUC12.

Table A-6-2. Percentage contribution of total Hg sources delivered to each impaired WBID^a.

WBID	Geologic background load (g/yr)	Near-channel load (g/yr)	Wet atmospheric deposition (g/yr)	Dry atmospheric deposition to water (g/yr)	Point source load (g/yr)
Peña Blanca Lake (AZL15050301-1070)	2.6%	0.1%	78.5%	18.8%	0.0%
Parker Canyon Lake (AZL15050301-1040)	<0.1%	<0.1%	59.9%	40.0%	0.0%
Patagonia Lake (AZL15050301-1050)	44.1%	28.1%	23.4%	2.1%	2.4%
Arivaca Lake (AZL15050304-0080)	<0.1%	<0.1%	69.5%	30.5%	0.0%
Scott Reservoir (AZL15020005-1360)	11.6%	9.9%	76.5%	2.0%	0.0%
Canyon Lake (AZL15060106A-0250)	12.6%	18.7%	65.6%	3.2%	<0.1%
Apache Lake (AZL15060106A-0070)	15.0%	20.9%	61.2%	2.9%	<0.1%

WBID	Geologic background load (g/yr)	Near-channel load (g/yr)	Wet atmospheric deposition (g/yr)	Dry atmospheric deposition to water (g/yr)	Point source load (g/yr)
Bartlett Lake (AZL15060203-0110)	16.2%	28.0%	53.5%	1.8%	0.5%
Lake Pleasant (AZL15070102-1100)	16.8%	48.6%	25.7%	4.0%	5.0%
Becker Lake ^b (AZL15020001-0150)	47.0%	43.7%	8.3%	1.0%	0.0%
Horsethief Lake ^b (AZL15070102-0630)	73.2%	0.0%	13.3%	13.5%	0.0%
Willow Springs Lake (AZL15020010-1670)	2.6%	0.0%	82.3%	15.1%	0.0%
Black Canyon Lake (AZL15020010-0180)	10.0%	0.0%	83.2%	6.8%	0.0%
Alamo Lake (AZL15030204-0040A)	29.5%	39.4%	28.7%	2.4%	<0.1%
Lyman Reservoir (AZL15020001-0850)	58.2%	28.1%	12.9%	0.9%	0.0%
Soldiers Annex Lake (AZL15020008-1430)	60.5%	9.3%	20.4%	9.8%	0.0%
Soldiers Lake (AZL15020008-1440)	65.9%	<0.1%	23.1%	11.1%	0.0%

WBID	Geologic background load (g/yr)	Near-channel load (g/yr)	Wet atmospheric deposition (g/yr)	Dry atmospheric deposition to water (g/yr)	Point source load (g/yr)
Long Lake (Lower) (AZL15020008-0820)	60.1%	11.0%	19.6%	9.4%	0.0%
Lake Mary (Upper) (AZL15020015-0900)	5.3%	9.9%	77.3%	7.6%	0.0%
Lake Mary (Lower) (AZL15020015-0890)	14.7%	11.9%	64.9%	8.5%	0.0%
Santa Fe Reservoir ^b (AZL15010004-1340)	3.7%	0.0%	57.7%	38.6%	0.0%
Roosevelt Lake (AZL15060103-1240)	20.3%	26.0%	51.4%	2.3%	<0.1%
Devils Canyon (AZ15050100-1662)	1.5%	35.0%	61.2%	2.3%	0.0%
Mineral Creek (AZ15050100-012B)	1.6%	62.7%	34.5%	1.2%	0.0%
Tonto Creek (AZ15060105-009)	14.0%	33.1%	52.2%	0.7%	0.0%
Tonto Creek (AZ15060105-004)	11.8%	35.8%	50.1%	2.3%	0.0%
Tonto Creek (AZ15060105-006)	12.7%	35.8%	50.5%	0.9%	0.0%
Tonto Creek (AZ15060105-013B)	15.0%	37.6%	46.8%	0.6%	0.0%

WBID	Geologic background load (g/yr)	Near-channel load (g/yr)	Wet atmospheric deposition (g/yr)	Dry atmospheric deposition to water (g/yr)	Point source load (g/yr)
Tonto Creek (AZ15060105-011)	12.3%	37.5%	49.6%	0.6%	0.0%
Tonto Creek (AZ15060105-008)	14.3%	36.6%	48.3%	0.9%	0.0%

- a. Results are calculated at the HUC12 scale.
- b. Becker Lake, Horsethief Lake, and Santa Fe Reservoir results are adjusted to account for drainage areas containing fractions of a HUC12.

A-7.0 ESTIMATED THG CONCENTRATIONS IN IMPAIRED WBIDS

Instream THg concentration targets are established based on ambient chronic THg concentration criteria established in regulation or through exposure concentrations estimated to be consistent with achieving acceptable fish tissue concentrations, as discussed in Section A-3.3. The THg target is then compared to observed THg data and to the predicted concentration based on the simulated THg delivered load and the annual average flow rate of streams or residence time of lakes. In theory, the needed reductions are obtainable by comparison to the observed data alone – but for many of the impaired WBIDs observed water column THg data are sparse, non-existent, or only available from analytical methods that used reporting limits that are orders of magnitude larger than the target concentrations identified in Section A-3.3, which are in the 1 – 2 ng/L range. Therefore, a weight-of-evidence approach is used to determine reductions from observed and predicted water column concentrations as well as from fish tissue data. Furthermore, the predicted concentration data are tuned or calibrated to ensure consistency with available observation data.

A-7.1 PREDICTED THG CONCENTRATION ESTIMATES IN IMPAIRED WBIDS

The SPARROW-based analysis provides estimates of THg transport from source areas to impaired WBIDs after accounting for THg losses due to flow reductions (e.g., diversions) for dissolved Hg and due to sedimentation losses for solids-associated Hg. This tabulation relative to flow and sediment transport does not provide a complete accounting of THg transit losses — especially within lakes and reservoirs. Significant additional losses of THg mass may occur due to the complexation of ionic Hg with sulfide ions resulting in the formation and deposition of cinnabar (HgS) and through Hg methylation and photo-demethylation processes that result in loss of gaseous elemental Hg to the atmosphere. In some cases, there may be a net gain of THg to the water column due to the release from contaminated sediments. These processes occur primarily in lentic waterbodies and not in fast-flowing streams. We therefore expect that THg concentrations in impaired lakes will on average, but not always, be somewhat less than is predicted by the sum of watershed THg loads divided by watershed inflow.

For lakes and reservoirs, concentrations are estimated using steady-state mass balance models, adjusting for hydraulic retention time and sedimentation rates. Concentration

calculations are similar to simple models for average lake phosphorus concentration (summarized in Jacoby and Welch, 2004, pages 178-179): A simplified steady-state lake mass balance concentration (C) is estimated as $C = C_i / (1 + \sigma\tau)$, where C_i is the average flow-weighted input concentration (annual load divided by flow), τ is the hydraulic retention time (V/Q), and σ is a net loss/sedimentation rate. σ can be estimated from site-specific data when available, but (for phosphorus) the steady-state concentration can be further approximated as $C = C_i / (1 + \tau^{0.5})$. We use the latter form as an initial starting point, then adjust the loss rate, σ , to match the observed range of concentrations.

For stream segments, the concentrations are approximated by considering flow, mass loading, and losses due to withdrawals, diversions, and kinetic processes. C is initially approximated by C_i , where C_i for a given reach is equal to $(M - L)/Q$, where M is the mass loading to the stream segment, Q is flow, and L is the mass loss due to diversions. To allow for adjustment to observations the final concentration is written in the same form as for lakes [$C = C_i / (1 + \sigma\tau)$]; however, the residence time for stream segments is not available from SPARROW so the unitless product $\sigma\tau$, henceforth referred to as S , is adjusted to be consistent with data. Thus, the final concentration in the impaired water body is $C = C_i / (1 + S)$.

A-7.2 CALIBRATION TO OBSERVED DATA

Calibration adjustments to observed concentration are made for each WBID individually. This allows direct calculation of loading capacity from the concentration equation adjusted for sedimentation and other loss processes. In the case of nested impairments, the approach means that the “sedimentation” adjustment represents the net effects of all upstream impoundments. This also prevents estimates for downstream impoundments from being biased by anomalous concentration results in upstream impoundments.

A-7.2.1 THg Data

THg observations with low reporting limits (< 5 ng/L) are available for 18 out of 30 impaired WBIDs (excluding Lake Powell). The count of observations by WBID ranges from 1 to 92 and there is considerable uncertainty as to how representative small sample sizes are for long-term average concentrations. Concentrations were summarized by both average and median. For two WBIDs, average concentrations appeared to be skewed by one very high anomalous data point. For these sites, the median is likely a better representation of the time-averaged exposure concentration.

A-7.2.2 Inferred Concentrations from Fish Tissue Data

WBIDs that lack adequate low-level THg concentration data were generally listed as impaired based on fish tissue data of at least 5 samples of one species. These fish tissue data can be used to back-calculate an estimate of the local THg exposure concentrations. Specifically, the BAF is a ratio that predicts fish concentration, F , from exposure concentration, E : F (mg/kg) = E (mg/L) x BAF (L/kg). Therefore, the exposure concentration can be approximated as $E = F/BAF$. The relationship is approximate as it ignores the uncertainty in the BAF calculations but is useful for range finding in the absence of other data. This calculation was performed using the length standardized average and maximum fish tissue sample from largemouth bass, where available, as this target species had the most data for BAF calculations (Section A-3.2).

In two instances the listing based on elevated fish tissue concentrations used species that are not target species in this TMDL analysis. The fish tissue-based listings for Tonto Creek reported results for numerous species, but, of our selected TL4 target species, only one largemouth bass

sample was collected. There were, however, numerous smallmouth bass analyses, also a TL4 species, but one for which we do not have a calculated AZ-specific BAF estimate. For this analysis, we have combined the smallmouth and largemouth bass samples and assumed that the BAF for largemouth is appropriate.

Santa Fe Reservoir, draining Cataract Canyon in Williams, AZ, was listed as impaired based on 5 black crappie fish tissue samples. No low reporting limit water column samples are available for this waterbody. Black crappie is a TL3 species, and we do not have data for an AZ-specific BAF. We therefore estimated corresponding water column exposure concentrations based on EPA's (2001) nationally recommended BAF for MeHg of 6.8×10^5 L/kg (USEPA, 2001, Table A-9) combined with the recommended THg to MeHg translator of 0.014 yields a BAF relative to THg of $9.5z \times 10^3$. The applicability of these national estimates to Arizona systems is uncertain, but, if correct, this THg BAF suggests there must be high THg exposure concentrations in Santa Fe Reservoir due to unknown sources (perhaps an unknown spill into this small waterbody) because no legacy mining activity is documented for the upstream part of Cataract Canyon nor are there any upstream permitted point source discharges.

The rationale for selecting consensus THg concentrations for adjusting SPARROW results is shown in Table A-7-1. Preference is given to average observed THg data when there are data available with a low reporting limit. The median, which is less susceptible to outliers, is used when the data set contains 5 or fewer observations or appears to be highly leveraged by an extreme outlier. Where no observed THg data are available estimates based on fish tissue concentration from the species with the most extensive data are used. We choose the average estimate for small lakes, where concentrations are more likely to be spatially homogenous, and the maximum estimate for larger lakes where exposure concentrations are likely to be more variable. Where both fish-based estimates and a limited number of observed THg concentrations are available, a compromise value is selected.

Table A-7-1. Consensus THg concentration values for calibrating SPARROW model results.

WBID	Average Observed THg Conc (ng/L; low RL)	Median Obs THg Conc (ng/L; low RL)	Obs. THg count	THg from fish tissue (ng/L)	Consensus THg Conc. (ng/L)	Notes on consensus value
Peña Blanca Lake (AZL15050301-1070)	6.52	5.12	34	5.68- 12.79	6.5	Use observed average
Parker Canyon Lake (AZL15050301-1040)	4.54	3.06	36	0.00- 6.66	4.5	Use observed average
Patagonia Lake (AZL15050301-1050)	0.81	N/A	1	1.10- 1.89	1.89	Maximum from LMB
Arivaca Lake (AZL15050304-0080)	15.91	11.9	5	0.00- 8.00	11.9	Median (small sample)

WBID	Average Observed THg Conc (ng/L; low RL)	Median Obs THg Conc (ng/L; low RL)	Obs. THg count	THg from fish tissue (ng/L)	Consensus THg Conc. (ng/L)	Notes on consensus value
Scott Reservoir (AZL15020005-1360)	N/A	N/A	N/A	2.16- 4.13	3.16	CCF-average (small lake)
Canyon Lake (AZL15060106A-0250)	0.79	0.79	1	0.00- 1.66	1.66	LMB max (large lake)
Apache Lake (AZL15060106A-0070)	0.59	0.48	5	1.97- 3.33	3.33	LMB max (large lake)
Bartlett Lake (AZL15060203-0110)	N/A	N/A	N/A	0.62- 3.80	4.45	CCF max (large lake)
Lake Pleasant (AZL15070102-1100)	N/A	N/A	N/A	0.62- 3.80	4.5	LMB max (large lake)
Becker Lake (AZL15020001-0150)	N/A	N/A	N/A	1.61- 1.94	1.61	LMB average
Horsethief Lake (AZL15070102-0630)	N/A	N/A	N/A	3.30- 4.70	3.3	LMB average
Willow Springs Lake (AZL15020010-1670)	1.23	1.16	6	1.57- 1.85	1.57	LMB average
Black Canyon Lake (AZL15020010-0180)	N/A	N/A	N/A	2.44- 2.78	2.44	LMB average
Alamo Lake (AZL15030204-0040A)	86.47	2.5	92	3.43- 6.18	3.43	LMB average
Lyman Reservoir (AZL15020001-0850)	5.19	2.04	29	4.14- 7.32	5.19	Observed average
Soldiers Annex Lake (AZL15020008-1430)	18.05	18.05	2	N/A	18.05	Observed average
Soldiers Lake (AZL15020008-1440)	8.19	8.03	10	N/A	8.19	Observed average

WBID	Average Observed THg Conc (ng/L; low RL)	Median Obs THg Conc (ng/L; low RL)	Obs. THg count	THg from fish tissue (ng/L)	Consensus THg Conc. (ng/L)	Notes on consensus value
Long Lake (Lower) (AZL15020008-0820)	14.97	9.17	5	N/A	14.97	Observed average
Lake Mary (Upper) (AZL15020015-0900)	13.49	12.6	33	0.00- 2.13	13.49	Observed average
Lake Mary (Lower) (AZL15020015-0890)	6.94	8.55	12	N/A	6.94	Observed average
Santa Fe Reservoir (AZL15010004-1340)	N/A	N/A	N/A	65.34- 72.48	70	Use black crappie data and national dMeHg BAF
Roosevelt Lake (AZL15060103-1240)	0.59	0.29	14	2.85- 5.34	5.34	LMB max (large lake)
Devils Canyon (AZ15050100-1662)	2345.83	30.5	6	N/A	30.5	Use median due to 7000 ng/L outlier
Mineral Creek (AZ15050100-012B)	792.22	17	9	N/A	17	Use median due to 7000 ng/L outlier
Tonto Creek (AZ15060105-009)	14.1	14.1	1	6.12	14.1	Observed (1 point)
Tonto Creek (AZ15060105-004)	N/A	N/A	N/A	N/A	1.88	No data; inferred from AZ15060105-006
Tonto Creek (AZ15060105-006)	N/A	N/A	N/A	1.88	1.88	From smallmouth bass and LMB BAF
Tonto Creek (AZ15060105-013B)	1.2	1.2	1	0.77	1.2	Observed (1 point)
Tonto Creek (AZ15060105-011)	250	N/A	N/A	N/A	10	No data; inferred from AZ15060105-009
Tonto Creek (AZ15060105-008)	14.1	N/A	1	6.12	10	Compromise

A-7.2.3 Model Calibration

Adjustments to the Hg loss rate were used to bring the model into agreement with the consensus concentrations from Table A-7-1. The results are shown in Table A-7-2.

Table A-7-2. SPARROW model THg calibration.

WBID	THg load (g/yr)	Outflow (cfs)	Volume (m ³)	Retention time (yr)	Calibrated loss factor (S, unitless)	Consensus THg (ng/L) (Table A-7-1)	Predicted THg (ng/L)
Peña Blanca Lake (AZL15050301-1070)	10	0.33	4.11E+05	1.40	4.42	6.50	6.50
Parker Canyon Lake (AZL15050301-1040)	14	0.13	9.92E+05	8.53	25.09	4.50	4.50
Patagonia Lake (AZL15050301-1050)	935	5.80	2.23E+06	0.43	94.38	1.89	1.89
Arivaca Lake (AZL15050304-0080)	15	0.20	6.57E+05	3.60	5.80	11.90	11.90
Scott Reservoir (AZL15020005-1360)	171	5.37	2.24E+05	0.05	10.26	3.16	3.16
Canyon Lake (AZL15060106A-0250)	28,584	589.44	2.56E+07	0.05	31.69	1.66	1.66
Apache Lake (AZL15060106A-0070)	30,450	584.44	9.01E+07	0.17	16.51	3.33	3.33
Bartlett Lake (AZL15060203-0110)	19,318	328.70	2.21E+07	0.08	13.78	4.45	4.45
Lake Pleasant (AZL15070102-1100)	6,454	34.74	2.53E+07	0.82	45.20	4.50	4.50
Becker Lake (AZL15020001-0150)	20	0.01	2.69E+05	27.38	1266.05	1.61	1.61
Horsethief Lake ^a (AZL15070102-0630)	8	0.13	2.47E+04	0.21	4.91	3.30	3.30

WBID	THg load (g/yr)	Outflow (cfs)	Volume (m ³)	Retention time (yr)	Calibrated loss factor (S, unitless)	Consensus THg (ng/L) (Table A-7-1)	Predicted THg (ng/L)
Willow Springs Lake (AZL15020010-1670)	61	2.16	5.23E+05	0.27	19.23	1.57	1.57
Black Canyon Lake (AZL15020010-0180)	27	1.22	3.37E+06	3.09	9.11	2.44	2.44
Alamo Lake (AZL15030204-0040A)	11,504	73.42	1.26E+08	1.92	50.12	3.43	3.43
Lyman Reservoir (AZL15020001-0850)	7,070	35.36	1.10E+07	0.35	42.11	5.19	5.19
Soldiers Annex Lake (AZL15020008-1430)	158	1.87	2.27E+05	0.14	4.24	18.05	18.05
Soldiers Lake (AZL15020008-1440)	140	1.94	1.89E+04	0.01	8.86	8.19	8.19
Long Lake (Lower) (AZL15020008-0820)	165	2.25	3.39E+05	0.17	4.46	14.97	14.97
Lake Mary (Upper) (AZL15020015-0900)	365	9.89	8.75E+06	0.99	2.06	13.49	13.49
Lake Mary (Lower) (AZL15020015-0890)	611	15.12	8.80E+06	0.65	5.52	6.94	6.94
Santa Fe Reservoir ^b (AZL15010004-1340)	10	0.83	5.55E+04	0.08	-0.92	70.00	70.00
Roosevelt Lake (AZL15060103-1240)	36,504	585.36	4.64E+08	0.89	12.07	5.34	5.34
Devils Canyon (AZ15050100-1662)	186	2.59	stream	N/A	1.63	30.50	30.50

WBID	THg load (g/yr)	Outflow (cfs)	Volume (m ³)	Retention time (yr)	Calibrated loss factor (S, unitless)	Consensus THg (ng/L) (Table A-7-1)	Predicted THg (ng/L)
Mineral Creek (AZ15050100-012B)	751	6.48	stream	N/A	6.63	17.00	17.00
Tonto Creek (AZ15060105-009)	4,849	58.13	stream	N/A	5.62	14.10	14.10
Tonto Creek (AZ15060105-004)	5,916	69.29	stream	N/A	49.79	1.88	1.88
Tonto Creek (AZ15060105-006)	5,523	68.89	stream	N/A	46.72	1.88	1.88
Tonto Creek (AZ15060105-013B)	1,619	24.37	stream	N/A	60.92	1.20	1.20
Tonto Creek (AZ15060105-011)	3,247	47.35	stream	N/A	6.67	10.00	10.00
Tonto Creek (AZ15060105-008)	5,181	63.87	stream	N/A	8.08	10.00	10.00

- a. *Outflow from Horsethief Lake is area-weighted because the drainage area is only a part of the SPARROW COMID.*
- b. *Outflow from Santa Fe Reservoir is area-weighted because the drainage area is only a part of the SPARROW COMID.*

A-8.0 LOAD CAPACITIES

The load capacity is the maximum amount of pollutant load that a waterbody can receive while still attaining water quality standards and supporting designated uses. Because Hg bioaccumulation in fish is a long-term chronic process, we first express the load capacity in terms of an annual load. TMDL regulations require that the load be expressed on a daily basis, so this annual load is then translated to an average daily load. Final daily wasteload allocations (for permitted point sources) and load allocations (for nonpoint sources) are addressed in Section A-8.0.

The load capacities for Arizona’s Hg-impaired waterbodies are calculated using the annual average water quality targets of 1.349 ng/L (for lakes and reservoirs), and 1.974 ng/L (for streams) total recoverable Hg (Section A-3.3). The loading associated with these target concentrations is back-calculated from the final calibrated SPARROW-based models (Section

7.0).The predicted concentration (C* (ng/L), after accounting for sedimentation losses) can be written as

$$C^* = \frac{THg / Outflow}{1 + S} * K$$

where THg is the total Hg loading rate (g/yr), outflow is the flow rate leaving the WBID (cfs), S (unitless) is a factor that relates net Hg loss to the loss associated with sedimentation predicted by SPARROW, a function of the retention time for lake segments, and K is a units conversion factor (1.11905) to convert [(g/yr)/(ft³/sec)] to ng/L units. Given a target C* associated with the loading capacity, C_L, THg is equal to the load capacity (LC) when

$$LC = THg = C_L \times Outflow * (1 + S) * 1/K$$

The resulting LC can be specified on a daily basis if outflow has per day units. Table A-8-1 displays the resulting estimated load capacities by WBID

Table A-8-1. Load capacities by WBID.

WBID	Outflow rate (cfs)	Load adjustment fraction	THg target (ng/L)	Adjusted loss rate (S)	Load Capacity THg (g/yr)
Peña Blanca Lake (AZL15050301-1070)	0.33	1	1.349	4.42	2.15
Parker Canyon Lake (AZL15050301-1040)	0.13	1	1.349	25.09	4.10
Patagonia Lake (AZL15050301-1050)	5.80	1	1.349	94.38	667.14
Arivaca Lake (AZL15050304-0080)	0.20	1	1.349	5.80	1.67
Scott Reservoir (AZL15020005-1360)	5.37	1	1.349	10.26	72.92
Canyon Lake (AZL15060106A-0250)	589.44	1	1.349	31.69	23,228.64
Apache Lake (AZL15060106A-0070)	584.44	1	1.349	16.51	12,335.55
Bartlett Lake (AZL15060203-0110)	328.70	1	1.349	13.78	5,856.23
Lake Pleasant (AZL15070102-1100)	34.74	1	1.349	45.20	1,934.63

WBID	Outflow rate (cfs)	Load adjustment fraction	THg target (ng/L)	Adjusted loss rate (S)	Load Capacity THg (g/yr)
Becker Lake (AZL15020001-0150)	0.01	2.61%	1.349	1,266.05	643.74
Horsethief Lake (AZL15070102-0630)	0.13	29.41%	1.349	4.91	3.21
Willow Springs Lake (AZL15020010-1670)	2.16	1	1.349	19.23	52.75
Black Canyon Lake (AZL15020010-0180)	1.22	1	1.349	9.11	14.88
Alamo Lake (AZL15030204-0040A)	73.42	1	1.349	50.12	4,524.56
Lyman Reservoir (AZL15020001-0850)	35.36	1	1.349	42.11	1,837.78
Soldiers Annex Lake (AZL15020008-1430)	1.87	1	1.349	4.24	11.80
Soldiers Lake (AZL15020008-1440)	1.94	1	1.349	8.86	23.02
Long Lake (Lower) (AZL15020008-0820)	2.25	1	1.349	4.46	14.84
Lake Mary (Upper) (AZL15020015-0900)	9.89	1	1.349	2.06	36.46
Lake Mary (Lower) (AZL15020015-0890)	15.12	1	1.349	5.52	118.84
Santa Fe Reservoir (AZL15010004-1340)	0.83	64.86%	1.349	-0.92	0.13
Roosevelt Lake (AZL15060103-1240)	585.36	1	1.349	12.07	9,221.73
Devils Canyon (AZ15050100-1662)	2.59	1	10	1.63	60.93
Mineral Creek (AZ15050100-012B)	6.48	1	10	6.63	441.67
Tonto Creek (AZ15060105-009)	58.13	1	1.974	5.62	678.84
Tonto Creek (AZ15060105-004)	69.29	1	1.349	49.79	4,242.99

WBID	Outflow rate (cfs)	Load adjustment fraction	THg target (ng/L)	Adjusted loss rate (S)	Load Capacity THg (g/yr)
Tonto Creek (AZ15060105-006)	68.89	1	1.349	46.72	3,962.91
Tonto Creek (AZ15060105-013B)	24.37	1	1.974	60.92	2,661.68
Tonto Creek (AZ15060105-011)	47.35	1	1.974	6.67	640.94
Tonto Creek (AZ15060105-008)	63.87	1	1.974	8.08	1,022.65

Note: Outflow rate is the annual average from SPARROW, load adjustment fraction modifies SPARROW input estimates where a WBID drains only a portion of a COMID or diverts a portion of a reach. The THg concentration target is specified by waterbody type in Section A-3.0, the adjusted loss rate (S) is as specified in Table A-7-2, and the Load Capacity is the loading that achieves the target concentration based on the outflow and sedimentation rates. For Tonto Creek, WBID AZ15060105-004 is classified as a stream segment but falls within the normal pool footprint of Lake Roosevelt while WBID AZ15060105-004 extends to the edge of Lake Roosevelt. These WBIDs have therefore been assigned the more conservative fish tissue-based water column target calculated for lakes and reservoirs. Neither of these WBIDs would be considered to be impaired relative to the 1.974 ng/L water column target.

Outflow rates for Becker Lake and Santa Fe Reservoir are adjusted to account for the outlet being upstream of the COMID boundary. The negative net sedimentation rate estimated for Santa Fe Reservoir suggests the presence of a significant source of Hg regeneration within the lake sediment.

A-9.0 NEEDED LOAD REDUCTIONS

The calculation of the load capacity for total Hg in Arizona’s impaired WBID watersheds indicates that large reductions in existing Hg loads are needed to attain the target annual average water column THg concentrations. The reductions calculated to achieve the load capacities calculated in Section A-8.0 are shown in Table A-9-1. The reduction percentages range from zero to 98 percent with a median of 70 percent. The zero percent reduction is estimated in one segment of Tonto Creek (AZ15060105-013B) that lacks evidence of impairment from either water column or fish tissue data obtained within the WBID.

Table A-9-1. Needed percent reductions in total Hg loads to achieve TMDL targets.

WBID	Existing THg consensus concentration (ng/L)	Existing THg effective load (g/yr)	Load Capacity THg (g/yr)	5% MOS (g/yr)	Remaining loading capacity (g/yr)	Needed load reduction
Peña Blanca Lake (AZL15050301-1070)	6.50	10.3	2.1	0.1	2.0	80.3%
Parker Canyon Lake (AZL15050301-1040)	4.50	13.7	4.1	0.2	3.9	71.5%
Patagonia Lake (AZL15050301-1050)	1.89	934.7	667.1	33.4	633.8	32.2%
Arivaca Lake (AZL15050304-0080)	11.90	14.8	1.7	0.1	1.6	89.2%
Scott Reservoir (AZL15020005-1360)	3.16	170.8	72.9	3.6	69.3	59.4%
Canyon Lake (AZL15060106A-0250)	1.66	28,583.8	23,228.6	1,161.4	22,067.2	22.8%
Apache Lake (AZL15060106A-0070)	3.33	30,450.2	12,335.5	616.8	11,718.8	61.5%
Bartlett Lake (AZL15060203-0110)	4.45	19,318.2	5,856.2	292.8	5,563.4	71.2%
Lake Pleasant (AZL15070102-1100)	4.50	6,453.5	1,934.6	96.7	1,837.9	71.5%
Becker Lake (AZL15020001-0150)	1.61	768.3	643.7	32.2	611.6	20.4%
Horsethief Lake (AZL15070102-0630)	3.30	7.8	3.2	0.2	3.0	61.2%
Willow Springs Lake (AZL15020010-1670)	1.57	61.4	52.7	2.6	50.1	18.4%
Black Canyon Lake (AZL15020010-0180)	2.44	26.9	14.9	0.7	14.1	47.5%

WBID	Existing THg consensus concentration (ng/L)	Existing THg effective load (g/yr)	Load Capacity THg (g/yr)	5% MOS (g/yr)	Remaining loading capacity (g/yr)	Needed load reduction
Alamo Lake (AZL15030204-0040A)	3.43	11,504.3	4,524.6	226.2	4,298.3	62.6%
Lyman Reservoir (AZL15020001-0850)	5.19	7,070.5	1,837.8	91.9	1,745.9	75.3%
Soldiers Annex Lake (AZL15020008-1430)	18.05	157.9	11.8	0.6	11.2	92.9%
Soldiers Lake (AZL15020008-1440)	8.19	139.7	23.0	1.2	21.9	84.4%
Long Lake (Lower) (AZL15020008-0820)	14.97	164.7	14.8	0.7	14.1	91.4%
Lake Mary (Upper) (AZL15020015-0900)	13.49	364.6	36.5	1.8	34.6	90.5%
Lake Mary (Lower) (AZL15020015-0890)	6.94	611.4	118.8	5.9	112.9	81.5%
Santa Fe Reservoir (AZL15010004-1340)	70.00	6.8	0.1	0.0	0.1	98.2%
Roosevelt Lake (AZL15060103-1240)	5.34	36,504.1	9,221.7	461.1	8,760.6	76.0%
Devils Canyon (AZ15050100-1662)	30.50	185.8	60.9	3.0	57.9	68.9%
Mineral Creek (AZ15050100-012B)	17.00	751.0	441.7	22.1	419.6	44.1%
Tonto Creek (AZ15060105-009)	14.10	4,849.1	678.8	33.9	644.9	86.7%
Tonto Creek (AZ15060105-004)	1.88	5,916.0	4,243.0	212.1	4,030.8	31.9%
Tonto Creek (AZ15060105-006)	1.88	5,522.8	3,962.9	198.1	3,764.8	31.8%

WBID	Existing THg consensus concentration (ng/L)	Existing THg effective load (g/yr)	Load Capacity THg (g/yr)	5% MOS (g/yr)	Remaining loading capacity (g/yr)	Needed load reduction
Tonto Creek (AZ15060105-013B)	1.20	1,619.2	2,661.7	133.1	2,528.6	0.0%
Tonto Creek (AZ15060105-011)	10.00	3,246.9	640.9	32.0	608.9	81.2%
Tonto Creek (AZ15060105-008)	10.00	5,181.0	1,022.6	51.1	971.5	81.2%

Note: The existing THg consensus concentration is presented in Table A-7-1; the existing THg effective load is the average annual load rate that yields the consensus concentration based on outflow and calibrated sedimentation/loss rates; the load capacity is from Table A-8-1; the needed reduction is equal to (THg effective load – load capacity) / THg effective load.

A-10.0 KEY ASSUMPTIONS OF THE TMDL ANALYSIS

The analytical approach for developing statewide Hg TMDL calculations for Arizona is based on several key assumptions:

A-10.1 TMDL Target Specification

- The TMDL target is defined as a long-term, time-based average concentration for each water type (stream, lake/reservoir) and fish species. This approach accounts for Hg's chronic and bioaccumulative nature.
- Bioaccumulation factor (BAF) analysis establishes site-specific targets, which are used to calculate a geometric mean across all water type-fish species pairs. The target is expressed as total Hg (THg) due to the availability of more extensive environmental data compared to MeHg.
- The target concentration is also expressed as a maximum daily load (MDL) to comply with TMDL regulations.

A-10.2 Mass Balance Calculations:

- Average source loads are converted to concentrations using simple mass balance calculations, utilizing flow data from the National Water-Balance Model (same basis used by SPARROW).
- For lakes/reservoirs, concentrations are estimated using steady-state mass balance models, adjusting for hydraulic retention time and sedimentation rates. Concentration calculations follow a method based on simple mass-balance models of particle-reactive constituents in lakes, originally developed for phosphorus analysis as summarized in Jacoby and Welch (2004), pages 178-179. A simplified steady-state lake mass balance

concentration (C) is estimated as $C = C_i / (1 + \sigma\tau)$, where C_i is the average flow-weighted input concentration (annual load divided by flow), τ is the hydraulic retention time (V/Q), and σ is a net loss/sedimentation rate. σ can be estimated from site-specific data when available, but the steady-state concentration can be further approximated as $C = C_i / (1 + \tau^{0.5})$.

- For stream segments, the concentrations are approximated by considering flow, mass loading, and losses due to withdrawals and diversions. C is approximated by C_i , where C_i for a given reach is equal to $(M - L)/Q$, where M is the mass loading to the stream segment, Q is flow, and L is the mass loss due to diversions. For streams, THg mass loss is assumed to be equal to the sediment mass loss simulated by the SPARROW model.

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ADDENDUM A: HG IN WATER ANALYTICAL METHODS

Hg monitoring data in Arizona have been collected by a variety of different agencies using a variety of analytical methods. These data were retrieved and supplied by ADEQ. There are certain anomalies in the data that must be accounted for, especially when the data are used for calculating ratios such as BAFs or sediment potency factors.

First, early data had incorrect units reported (e.g., mg/L instead of $\mu\text{g/L}$); therefore, when used to convert to a standard concentration basis as ng/L, led to unrealistically high THg concentrations (e.g., 180,000 ng/L), whereas the highest reported ambient concentrations found in data from other western mining-impacted streams (e.g., Domagalski et al. (2016) are in the 600 ng/L range). Second, many of the analytical methods for available observed data used older, high detection limit (DL) or high reporting limit (RL) analytical methods that do not provide the needed precision to calculate ratios (MeHg:TSS and sediment potency ratios) and were also prone to laboratory blank contamination. Many of these analytical methods had DLs/RLs of 500 ng/L or greater, whereas most ambient THg concentrations, including at impaired sites, are likely in the 1 – 150 ng/L range, with natural background often in the 2 – 5 ng/L range.

Preferably, only analyses that use EPA method 1631 for low-level THg analysis and method 1630 for low-level MeHg analysis with RLs < 1 ng/L, which was initiated in 2001, would be used for calculating ratios; however, that would limit the size and extent of the data. Certain other analyses with low DLs can also be included. There are a few other laboratory analytical methods (USGS method CV018, EPA 245.7, and SW 846) that used a similar cold vapor atomic absorption (CVAA) analysis to method 1631 but had a nominal DL of 5 ng/L, that appear acceptable for ratio analysis.

Much of the earlier Hg data used EPA method 245.1. Method 245.1 has a nominal detection limit of 200 ng/L (0.2 $\mu\text{g/l}$) for THg, which is too high for accurate analyses of BAFs, sediment potency, or MeHg:THg ratios; however, many ADEQ samples (mostly from the mid-2000s) used Method 245.1 and stated reporting limits (RLs) of < 1 ng/L with laboratory QA/QC approval. This is not implausible as the analysis can achieve lower RL levels with larger sample volumes than in the standard 245.1 method document; however, there may be other reasons to question the accuracy of Method 245.1 results due to refinements in eliminating interferences and laboratory contamination with EPA methods 1630 and 1631. About 10% of the Method 245.1 results note low-level RLs, while the majority have the standard RL equivalent to 200 ng/L.

In summary, data exclusions occurred for different reasons across different analyses, and there was no single exclusion logic applied uniformly to all datasets. Examples include: older datasets were excluded due to analytical methods with insufficient detection limits; QA/QC samples (blanks, replicates), non-ambient samples, and outfall-specific monitoring were excluded from ambient analyses; and, some analyses require paired fish tissue and water column data, while others do not.

ADDENDUM B. ANALYSIS FOR LAKE POWELL

Arizona's jurisdictional waters include a portion of Lake Powell, the massive impoundment upstream of the Grand Canyon on the Colorado River (Figure B-11-1). Arizona has not sampled fish tissue Hg concentrations in Lake Powell — but Lake Powell is documented to have elevated Hg concentrations within Utah waters. In reviewing Arizona's 2018 303(d) list, EPA indicated that Arizona should list its portion of Lake Powell as impaired based on high Hg tissue concentrations observed in striped bass (*Morone saxatilis*) in Utah waters.

The Utah Fish Tissue Contamination Program provided records of fish tissue Hg concentrations collected from 2005 to 2010. These include 123 striped bass Hg samples from nine stations in San Juan and Kane Counties, Utah. The striped bass tissue concentrations for Hg ranged from 0.301 to 1.3 mg/kg with a median of 0.424 mg/kg — thus all samples were greater than the Arizona fish tissue criterion of 0.3 mg/kg.

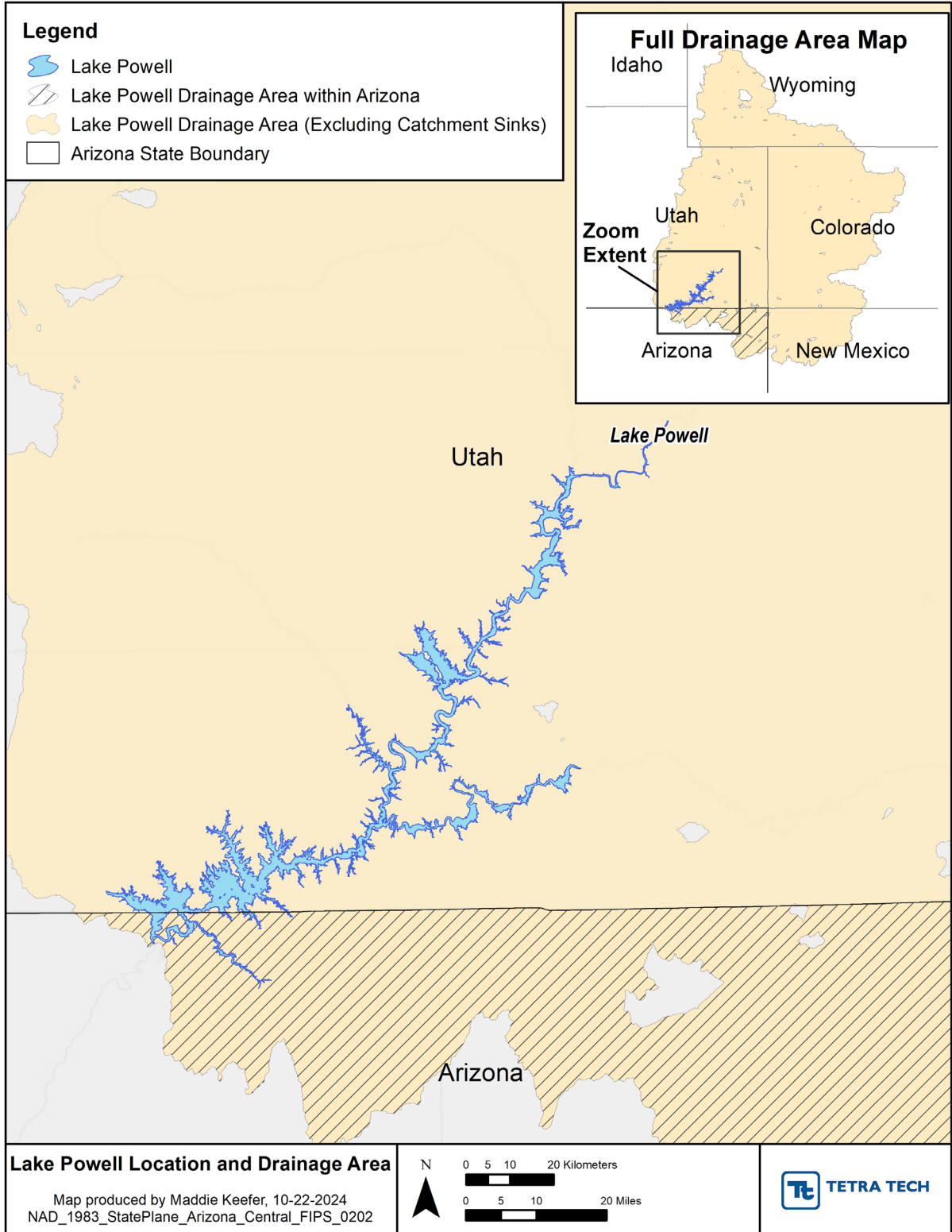


Figure B-11-1. Lake Powell Location and Drainage Area.

Because Arizona has not collected water column Hg samples from Lake Powell, a BAF analysis was not undertaken for these striped bass samples. Instead, needed reductions were estimated using the Reduction Factor method.

To apply the Reduction Factor method, it is first necessary to convert the samples to a standardized length. Arizona fishing regulations do not include a length limit for striped bass, so the samples were standardized to the median length of the sampled fish, 435 mm.

The standardization equation used for each sample i is:

$$\ln(\text{FishTissue}_i) = \alpha + \beta * \ln(\text{FishLength}_i) + e_i$$

where α is an intercept term, β is the slope coefficient relative to the natural logarithm of fish length, i is the sample index, and e_i denotes a residual error term accounting for deviation of the individual sample from the regression line. Variables were (natural) log-transformed to account for skew, approximate linearity, and ensure positive results. The resulting intercept and slope coefficients are -3.810 and 0.499, respectively. The overall regression is not statistically significant (standard error = 0.329, $R^2 = 0.049$); however, the individual coefficients are significantly different from zero, with probability values of 0.0027 for α and 0.0165 for β .

For each individual fish specimen, the Hg concentration is standardized to account for differences from the standard-length fish concentration. To standardize the observed fish tissue concentrations, the plotted point of each fish tissue sample was essentially "slid" parallel to the regression line toward the species standard length. For fish specimens that fall below the regression line of best fit, if that specimen were to grow to standard length, we expect the fish tissue concentration to be less than the standard length Hg concentration; for fish specimens above the line of best fit, if that specimen were to grow to standard length, we'd expect the fish tissue concentration to be greater than the standard length Hg concentration. This calculation is performed by adding the residual term e_i to the standard length natural logarithm Hg concentration for that sample. The residual term is calculated as the difference between the natural logarithm of the observed concentration and the regression-predicted average concentration at the observed length.

Once all the individual fish specimen data have been length standardized, the median (50th percentile) of the standardized fish tissue concentration is calculated. For the Lake Powell striped bass samples, this standardized median is 0.443 mg/kg, which is slightly higher than the unstandardized median of 0.424 mg/kg. The Reduction Factor is then calculated by comparing the standardized median to the Arizona fish tissue criterion of 0.3 mg/kg, indicating a needed reduction in exposure concentrations of $(0.424 - 0.3) / 0.424 = 32.3\%$ for Lake Powell in general.

The total watershed drainage area of Lake Powell totals about 276,135 km². It includes portions of Utah, Colorado, Wyoming, and New Mexico and includes significant gold and silver mining areas. The Arizona portion of the watershed (15,410 km²) constitutes only 5.6% of the total drainage area. Reducing Hg loading to Lake Powell will require cooperation across multiple states and multiple EPA regions. Therefore, a full TMDL for Lake Powell cannot be calculated as part of the Arizona Statewide Hg TMDL.

The small area within Arizona that does drain to Lake Powell is within the Navajo Nation and contains mostly ephemeral streams such as Navajo Creek and Kaibito Creek. The area does not contain other known Hg-impaired waterbodies, nor does it have igneous geology or a history of extensive gold, silver, or Hg mining. However, there is a contribution of Hg to Lake Powell derived from atmospheric deposition of Hg within this area. Reductions to atmospheric

deposition needed to address Arizona's other Hg-impaired waterbodies will also contribute to achieving reductions in Arizona's small contribution of Hg load to Lake Powell.