THE SIERRA FUND

Headwater Mercury Source Reduction STRATEGY

Reclaiming the Sierra Conference Edition

The Sierra Fund - October 17, 2019

Reclaiming the Sierra

A Conference to Address Historic Mining Impacts

Oct 16-18, 2019 – Grass Valley, California

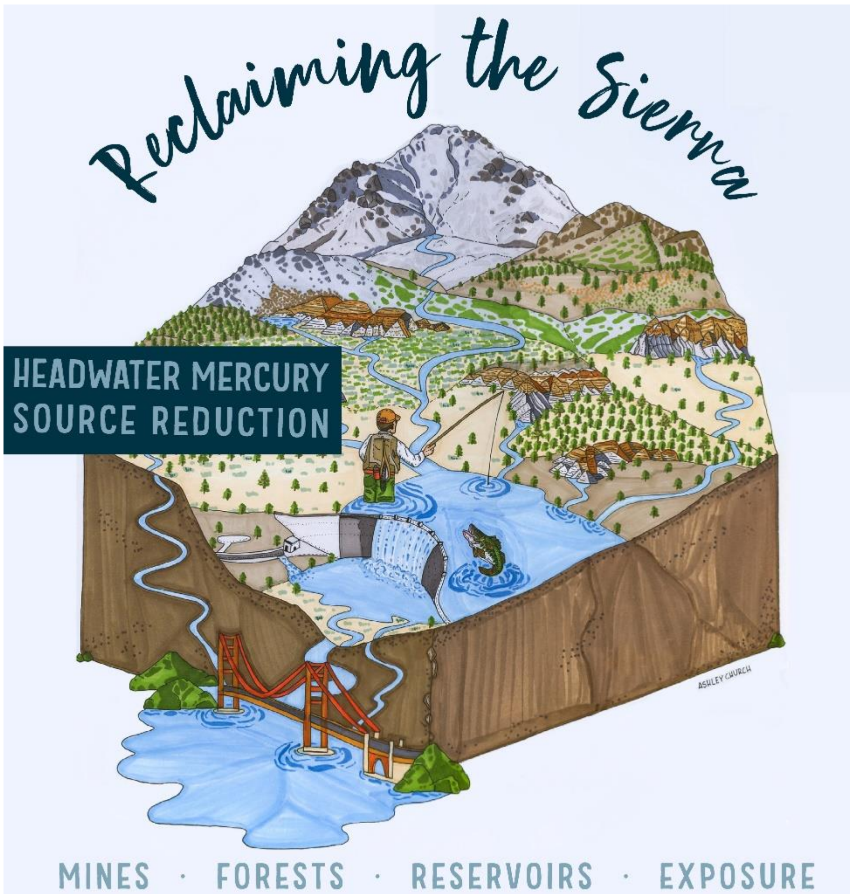

Illustration by: Ashley Church

The *Reclaiming the Sierra* conference is the West's primary venue for showcasing innovation in assessment and reclamation of mine-impacted landscapes. *Reclaiming the Sierra* was launched by The Sierra Fund in 2010 to provide strategic direction and a platform for action for a wide range of organizations exploring ways to restore ecosystem and community resiliency to California's headwaters devastated by gold mining. The 2019 event takes a multidisciplinary look at four targets for mercury abatement in the headwaters – hydraulic mines, forest and land management, contaminated sediment in reservoirs and the imminent threat to public health that mercury exposure poses.

About The Sierra Fund

Founded in 2001, The Sierra Fund's (TSF) mission is to protect and restore the resiliency of the ecosystems and communities of the Sierra Nevada. Since 2006 we have worked to build a body of research and cohort of scientists and leaders who stand beside us on the cutting edge of best-practices to address impacts of the California Gold Rush. Our programs have grown from the ground up to a regional approach thirteen years in the making sustained by over $3.5 million in foundation funding that we have successfully leveraged to secure nearly $4 million in government grants directly supporting our work.

In 2008 we released *Mining's Toxic Legacy*, the first comprehensive report detailing the impacts of historic mining, data gaps, and recommendations for action. Since then, we have conducted educational presentations in all 22 counties of the Sierra Nevada, held a biennial *Reclaiming the Sierra* (RTS) conference to convene experts and stakeholders, and released scientific studies to show the extent of contamination and human exposure. Key studies include our *Gold Country Recreational Trails and Abandoned Mines Assessment* (2010), *The Gold Country Angler Survey* (2011 and 2018), *Environmental Health Outreach Program Report* (2014), *Humbug Creek Watershed Assessment and Management Recommendations* (2015), and Fish Consumption Advisory Posting Protocol (2017). Copies of these documents as well as more information about our work may be obtained online at *www.sierrafund.org* or by contacting The Sierra Fund directly.

In 2017, TSF launched our Headwater Mercury Source Reduction (HMSR) Project, a watershed wide strategy to abate legacy mercury contamination that builds on the lessons learned from our work at Combie Reservoir and at Malakoff Diggins State Historic Park (MDSHP), which were allocated a combined $14 million dollars in the Governor's 2017/18 budget.

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Photo by: Alex Keeble-Toll

The Headwater Mercury Source Reduction Strategy would not have been possible without the dedicated engagement of the many technical experts and stakeholders who participate in The Sierra Fund's Headwater Mercury Source Reduction (HMSR) Technical Advisory Committee (TAC).

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HEADWATER MERCURY SOURCE REDUCTION STRATEGY

OVERVIEW

The Problem

Gold and mercury mining activities during the 19th century Gold Rush left California with a legacy of pollution that has persisted for over 160 years. Historic hydraulic mines are scattered across headwater forests and continue to release mercury with every storm event. See Figure 1. As a result, mercury contamination of Gold Country waterbodies is widespread, as demonstrated by Clean Water Act (CWA) Section 303(d) listings for mercury impairment and mercury is found in the aquatic food web from the Sierra to the sea, explaining the large number of state-issued fish consumption advisories based on mercury.

Research has shown that mercury is not only incorporated into the local food web at mine sites, but that it continues to be transported off of mine-impacted lands and that environments downstream of mercury sources including reservoirs can provide the conditions necessary for mercury to methylate, enter the food web, and biomagnify and bioaccumulate in fish (Fleck et al., 2011; Marvin-DiPasquale et al., 2011; Monohan, 2015; Saiki et al., 2009). The consumption of mercury contaminated fish is the primary pathway of human exposure and the high levels of mercury found in upper-trophic level Sierra Nevada species including black bass represents a potential threat to public health (Shilling et al., 2010; Monohan, 2011; Monohan and Keeble-Toll, 2018; California Environmental Protection Agency (CalEPA), 2003; OEHHA, 2008). Mercury can also have repercussions on the health of wildlife that eat fish, including birds (Ackerman et al., 2015).

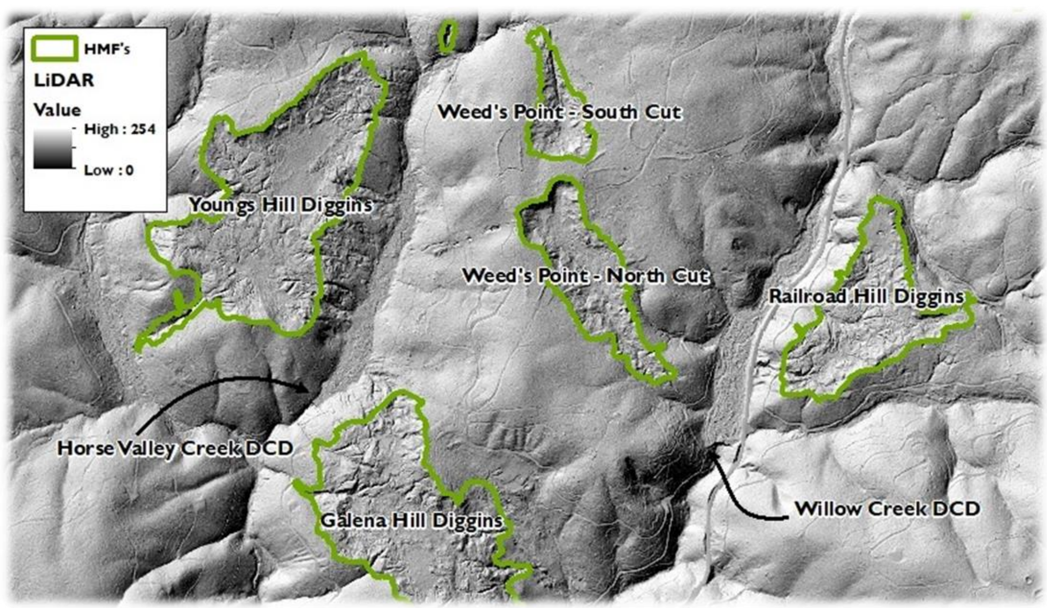

Figure 1: ***Headwater Sources of Mercury***
LiDAR for United States Forest Service (USFS) Tahoe National Forest (TNF) is being used to identify and delineate hydraulic mines and mine features, a principal source of mercury in the headwaters, that would be difficult to locate with aerial imagery or through on-the-ground reconnaissance due to forest density around the sites.

The Strategy

The Headwater Mercury Source Reduction (HMSR) Strategy is a living document intended to guide the protection and restoration of ecosystem and community resiliency in the Sierra Nevada to the benefit of both regional and downstream stakeholders. The HMSR Strategy builds on over a decade of research, actions, and methods, providing a cohesive platform for technical experts to share, revise, and integrate best-practices for the assessment and mitigation of mercury. By documenting and updating an informed approach to reduce headwater sources of mercury, the Strategy can be improved and leveraged toward the identification and execution of future projects.

Geographic Focus

For the purposes of this document, TSF uses the definition for the Sierra Nevada that is consistent with the boundary of the Sierra Nevada Conservancy, a state agency serving the region. Using this boundary, the Sierra Nevada consists of all or part of twenty-two counties and is the source of 60% of California's developed water supply (Sierra Nevada Conservancy, 2014). The primary geographic scope for implementation of the HMSR Strategy are those headwater regions that lie in and around the Gold Country of the Sierra Nevada. See Figure 2. However, given watershed-wide mercury fate and transport processes, the input and participation of stakeholders from all regions impacted by mercury statewide is valued and encouraged.

Figure 2: ***The Sierra Nevada Region***
The 22 counties of the Sierra Nevada are the primary geographic focus of the Headwater Mercury Source Reduction Strategy. Map Source: The Sierra Nevada Conservancy, http://www.sierranevada.ca.gov/our-region/maps.

Strategic Targets

Over the last decade, four primary targets have emerged as critical facets of headwater mercury contamination that must be addressed in order to protect and restore ecosystem and community resiliency in the Sierra Nevada. These targets are:

1. Hydraulic Mines and Mine Features
2. Mercury in Forest and Land Management
3. Mercury-Contaminated Sediment in Reservoirs
4. Mercury Exposure via Fish Consumption

Target 1: Hydraulic Mines and Mine Features

Hydraulic mines and hydraulic mine features (HMFs) are primary sources of mercury in the headwaters. Of the more than 20 million pounds of mercury imported from the Coast Range to the Sierra Nevada for use in gold processing, an estimated 2-6 million pounds were lost to the environment. Hydraulic mine operations were associated with the highest levels of mercury loss. At the denuded sites of hydraulic mines, inorganic mercury adsorbs to fine silts and clays, which erode and become suspended during storm events. Despite the fact that unregulated hydraulic mining ceased in 1884, and many debris control dams (DCDs) were built to hold back hydraulic mine waste, there is inorganic mercury washing off of hydraulic mine impacted sites, especially during storm events. This allows for mercury to be transported into aquatic ecosystems where it can methylate and become incorporated into the food web. (See https://www.sierrafund.org/projects/malakoff-diggins/ for additional information).

- **1A: Strategy**: Develop and apply best available technologies (BATs) and methods to prioritize and remediate mercury contamination sources in the headwaters.

- **1B: Outcome:** Remediated mines and mine features to reduce mercury contamination of downstream water bodies (including the Bay-Delta).

Target 2: Mercury in Forest and Land Management

Legacy mines in the Sierra are a complicating factor for forest management. Hydraulic mines consist of altered landscapes where hilltops were excavated to recover gold. These areas are typically partially vegetated with dense manzanita and madrone, leading to very high fuel loading. Mercury remains in the soils and can be transported into waterways and downstream reservoirs. The effect of wildfire on watershed health in a region with numerous hydraulic mine sites and unprecedented fuel loads has resulted in sedimentation and volatilization events and unknown releases of mercury. Forest fires occurring in the hydrologic path between these sites and stream channels may result in swift and significant transport of sediment and mercury into vulnerable water bodies due to loss of the buffering function of the forest.

- **2A: Strategy**: Develop and apply best available technologies and methods for prioritizing fuels reduction projects to reduce wildfire impacts in the vicinity of hydraulic mines.

- **2B: Outcome:** Reduced wildfire impacts to hydraulic mines including reduced transport of mercury into aquatic ecosystems from erosion of mercury-contaminated sediment and/or volatilization and subsequent atmospheric deposition of mercury.

Target 3: Mercury-Contaminated Sediment in Reservoirs

Until recently, addressing mercury loading associated with abandoned mines was not considered a high priority strategy for the Bay-Delta because there was the erroneous assumption that foothill reservoirs were holding back mercury. The reservoirs, however, are filling up with mercury-contaminated sediment and their trapping efficiency is decreasing. In addition, scientific advancements indicate that even low levels of mercury in sediment and water are prone to methylation, leading to high levels in fish through biomagnification and bioaccumulation. Research suggests that mercury bound (adsorbed) to fine silts and clays that originate from hydraulic mine sites can be transported out or over the top of dams, meaning that when reservoirs spill turbid water during storm events, mercury is being delivered to downstream waterways including the Bay-Delta.
(See https://www.sierrafund.org/projects/combie-reservoir-project/ for additional information).

- **3A: Strategy**: Develop and apply best available technologies and methods to prioritize and remove mercury-contaminated sediment from reservoirs.

- **3B: Outcome:** Removal of mercury-contaminated sediment from reservoirs to provide multiple benefits including water storage space, sellable aggregate, recovered gold, and reduction of mercury methylation conditions.

Target 4: Mercury Exposure via Fish Consumption

Consumption of mercury contaminated fish is the primary pathway of human exposure to this developmental neurotoxin. As a result of mercury transported off-site from legacy mines, the vast majority of water bodies in the Sierra Nevada and the San Francisco Bay-Delta are listed as impaired for mercury under section 303(d) of the Clean Water Act. Numerous water bodies have state-issued fish consumption advisories for mercury, warning sensitive populations, including women and children, to avoid consumption of predatory fish such as bass altogether. Exposure to mercury during pregnancy can cause permanent neurological deficits in children and the effects of mercury exposure during childhood includes slow development, language and memory impairment, and attention disorders. (See https://www.sierrafund.org/projects/angler-survey/ for additional information).

- **4A: Strategy**: Develop and apply best available technologies and methods to increase the amount and accessibility of information about mercury and fish consumption advisories.

- **4B: Outcome:** Accessible, understandable, and actionable information on mercury in local fish species for residents and visitors of the Sierra Nevada to protect their health.

COLLABORATIVE CONTEXT

History of Partnership

In 2006 The Sierra Fund (TSF) carefully assembled a Working Group of over 60 technical, policy and agency experts to provide sound advice and feedback to our work to assess and address mining's toxic legacy in the Sierra Nevada. See https://www.sierrafund.org/mtl/ and https://www.sierrafund.org/about/working-group/ for details. Since that time our project development strategy has been directed in part by outcomes of annual Working Group meetings which are used to offer critical insight to key agencies and the public about progress, direction, and planning processes to confront impacts from the California Gold Rush. Through our sustained efforts to inform and include members of the public we have conducted outreach on our work to address legacy mercury sources in all 22 counties of the Sierra Nevada and given more than 25 site tours of hydraulic mine sites for agency leaders and members of the public.

As part of TSF's active role in the Cosumnes, American, Bear, Yuba (CABY) integrated regional water management (IRWM) group, in 2014 TSF received funding from DWR to lead a regional Mercury Forum. Between 2015-2017 the Forum met quarterly to share lessons learned around permitting, sampling, and remediation activities for a bundle of sediment and mercury abatement projects in the CABY watershed region. See Figure 3 and Figure 4. To date ten master's theses that address legacy mercury and sediment in our headwaters have been completed by California State University, Chico graduate students under the direction of TSF's Program Director (with the collaboration of additional technical experts) and additional theses are currently underway.

Figure 3: ***Mercury Forum at Malakoff Diggins***
Members of The Sierra Fund's DWR-funded regional Mercury Forum listen to a presentation on potential remediation options for the hydraulic pit while on a Forum tour of the legacy mine site. Photo Source: Alex Keeble-Toll.

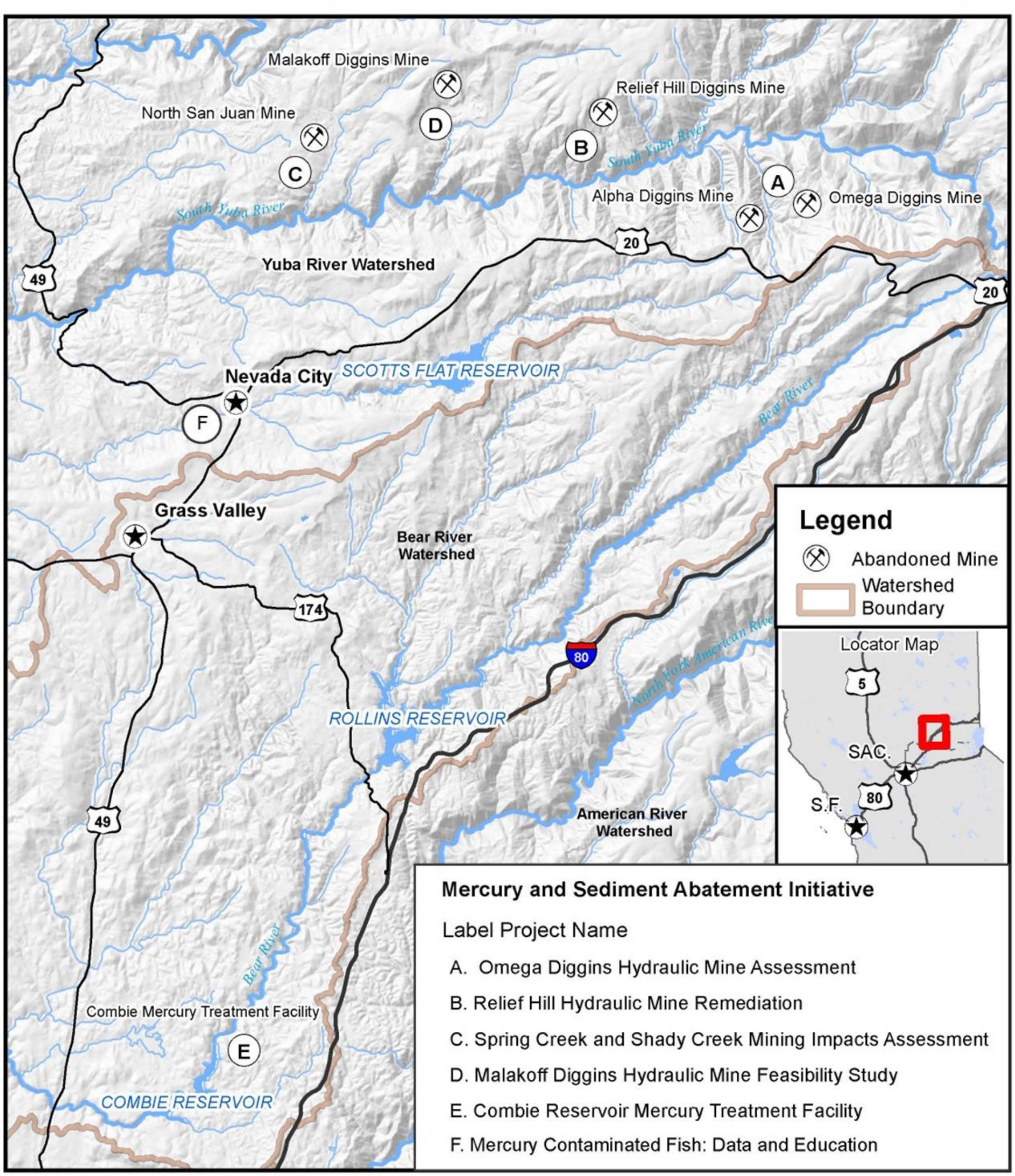

Figure 4: ***CABY Region Sediment and Mercury Abatement Projects***
Six sediment and mercury abatement projects in the CABY region were funded by the Department of Water Resources (2014-2018) and coordinated by the TSF-led regional Mercury Forum.

TSF launched the Headwater Mercury Source Reduction Technical Advisory Committee (HMSR-TAC) in 2017 as a way to leverage the outcomes of the Working Group and Mercury Forum and facilitate the development and implementation of a regional HMSR Strategy to address mercury contamination in Sierra Nevada watersheds. Each meeting features technical presentations that encourage discussion of each specific strategic target for mercury (hydraulic mine remediation, forest management and erosion, reservoirs and sediment management, or human exposure via fish consumption). Presentations are curated to frame the regional, local, and project specific issues and to stimulate discussion among TAC about the methodological approach to mercury abatement. This process also informs and refines the overall Strategy.

The HMSR Technical Advisory Committee (TAC) Partnership

The role of the HMSR-TAC Partnership is to inform and prioritize specific tasks associated with the implementation of the HMSR Strategy. This collaborative effort is sustained by the participation of regional and topical experts through quarterly TAC meetings convened and facilitated by The Sierra Fund. Meeting agendas, notes, and participant lists are developed and maintained by The Sierra Fund and made accessible on TSF's organizational website. See https://www.sierrafund.org/projects/hmsr-tac/ for additional information. Participants of TSF's HMSR-TAC have included advisors from:

- *California State University at Chico (CSU Chico)*
- *California Department of Public Heath (CDPH)*
- *Central Valley Regional Water Quality Control Board (CVRWQCB)*
- *Delta Tributaries Mercury Council (DTMC)*
- *California Department of Conservation (CDOC), Abandoned Mine Lands Unit (AMLU)*
- *Delta Mercury Exposure Reduction Program (Delta MERP)*
- *Environmental Justice Water Coalition*
- *Forsgren and Associates*
- *Great Lakes Environmental*
- *KTC Environmental*
- *McCord Environmental*
- *Mid-Klamath Watershed Council (MKWC)*
- *Nevada Irrigation District (NID)*
- *NV5 (formerly Holdrege and Kull)*
- *United States Forest Service (USFS), Plumas National Forest (PNF)*
- *Public Policy Institute of California (PPIC)*
- *Office of Environmental Health Hazard Assessment (OEHHA)*
- *Santa Clara Valley Water District (SCVWD)*
- *Sierra Forest Legacy*
- *South Yuba River Citizen's League (SYRCL)*
- *Sierra Nevada Conservancy (SNC)*
- *Sierra Institute for Community and Environment*
- *United States Forest Service (USFS), Tahoe National Forest (TNF)*
- *Teichert Construction*
- *University of California, Berkley*
- *University of California, Davis One Health*
- *University of South Carolina*
- *United States Environmental Protection Agency (USEPA)*

- *United States Geological Survey (USGS)*
- *Yuba Water Agency (YWA)*

The Partnership members listed in this living Strategy document are updated as new stakeholders are recruited to join the HMSR-TAC.

HEADWATER MERCURY SOURCES, TRANSPORT and EXPOSURE

Background

During the Gold Rush, elemental mercury (Hg) was transported to the Sierra Nevada from mercury mines located in the Coast Range on the west side of California's Central Valley (Hunerlach et al., 1999). See page 17, Figure 5. The imported mercury was used to facilitate processing at gold mines whereby gold was separated from ore using the amalgamation method (Bowie, 1905). The amalgamation method consisted of utilizing elemental Hg, which binds with gold, to form a gold-mercury amalgam. This amalgam settled out in sluice boxes and was collected and then heated, causing the Hg to volatilize and leaving the gold behind, a process known as "retort." Though the use of mercury improved historic gold recovery, not all of the Hg applied to a slurry formed an amalgam and not all of Hg was recovered from the retort process.

Mr. Bowie, a Gold Rush era mine engineer, knew that there was an unavoidable loss of Hg during the operation of a mine. With this understanding, Bowie utilized mine records to calculate how much Hg was lost based on the total weight of Hg used per run and the total weight of Hg recovered from amalgam. In the period of 1860 to 1880, it is estimated that about 11,800,000 kg (26 million pounds) of Hg was used in the Sierra Nevada and Klamath-Trinity Mountains alone and that of this 10-30% was lost to the environment (Bowie, 1905; Churchill, 2000). Mercury that was lost during the amalgam formation and recovery process persists as a contaminant at historic mine sites, often bound to fine silts and clays, and as a result water that transports sediment from legacy mines continues to be a source of Hg to the environment (Rytuba, 2005). Both mine waste and Hg-enriched sediment have been identified as sources of particulate bound mercury that can travel long distances and contaminate the aquatic environment (Rytuba, 2005, Fleck et al., 2011). In addition, liquid elemental Hg has been observed in sediment within hydraulic sluice tunnels and in bed sediment of Sierra Nevada rivers in historically mined regions (Hunerlach et al., 1999; Humphreys, 2005).

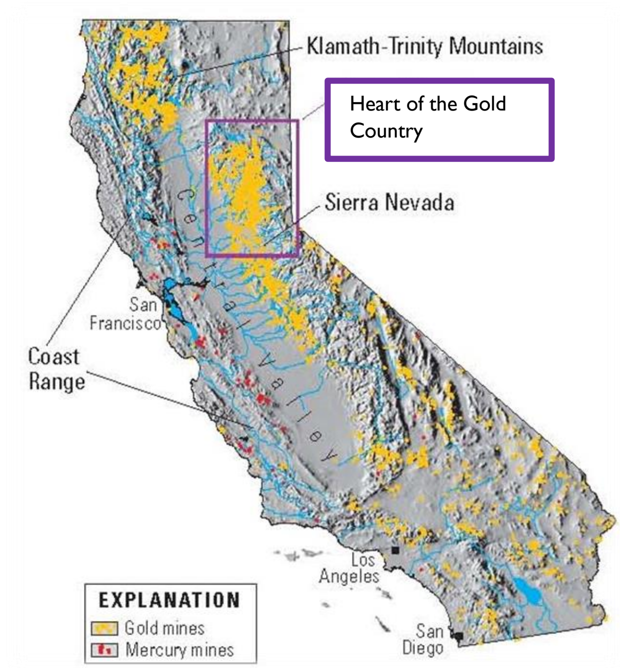

Figure 5: ***Gold and Mercury Mines of California***
Mercury was imported from the Coast Range to the Sierra Nevada for use in gold processing. Figure Source: USGS Fact Sheet 2005_3014_v1.1.

Forms of Mercury

Mercury in the environment originates from both natural and anthropogenic sources. Natural sources include volcanic eruptions, wild fires, and the ocean surface whereas anthropogenic sources include coal-fired power plants, waste incinerators, and the mining industries (Pacyna et al., 2003; UNEP, 2002). Mercury in freshwater is predominantly found in three forms: (1) ionic (HgII), (2) elemental (Hg0), and (3) organic methylmercury (CH_3Hg or MeHg). Different biotic and abiotic factors transform inorganic mercury into methylmercury (MeHg). Both inorganic and organic mercury forms are risks to human health and other living organisms in the environment. However, methylmercury is considered the most toxic form because it is a bioavailable neurotoxin that crosses the blood brain barrier (Steinwall and Olsson, 1969). The biotic and abiotic factors that contribute to mercury methylation include carbon, absence of oxygen, presence of sulfate or iron reducing bacteria, low pH, and bioavailability of mercury. Sulfate and iron-reducing bacteria, in the absence of oxygen, convert inorganic mercury (HgII) into methylmercury (MeHg) (Compeau and Bartha, 1984; Gilmour et al., 1992; Marvin-DiPasequale and Agee, 2003).

Both inorganic and organic mercury are risks to human health and other living organisms in the environment, but by different mechanisms. Inorganic mercury is often considered less toxic to living organisms; however, ingestion of 1 gram of inorganic mercuric chloride ($HgCl_2$) can cause death (Gleason et al., 1963). Inorganic mercury, if ingested through the gastro-intestinal (GI) track has a tendency to accumulate in the vital organs like the liver, kidneys, lungs and nervous tissue (Gochfeld, 2003). The Maximum Contaminant Level (MCL) for inorganic mercury in drinking water is 0.002 milligrams per liter or 0.002 parts per million, according to the EPA National Primary Drinking Water Regulation (USEPA, 2018).

The primary exposure route of organic mercury (MeHg) to humans is consumption of mercury-contaminated fish (Shilling et al., 2010). Exposure can cause mild to severe neurophysiological disorders in humans (Kurland et al., 1960). Methylmercury can be distributed not only between red blood cells and plasma, but also between blood and extravascular tissues (Eccles and Annau, 1987). Methylmercury in the membranous structures affects protein metabolism by altering the biochemical changes inside the cell (Yoshino et al., 1966). As a result of the public health threat, the United States Environmental Protection Agency (USEPA) has set water quality criteria for MeHg as a fish tissue concentration value (0.3 milligram MeHg per kilogram of wet-weight fish tissue) under the Clean Water Act (CWA) Section 304(a) (USEPA, 2000).

In 2017 the State Water Resources Control Board (SWRCB) adopted several mercury water quality objectives; the objective to protect fish consumption at a non-subsistence rate is 0.2 mg/kg. Fish is not only a popular low calorie source of protein, it is an important cultural food for many groups including Asian and Native Americans. Even though fish consumption varies widely by culture and ethnicity, according to the Office of Environmental Health Hazard Assessment (OEHHA), the fish consumption rate in California is on average, 16.1 to 61.3 grams per day, per person (OEHHA, 2001).

Regulation of Mercury

Mercury in aqueous and methylated form is regulated under the CWA and according to limits that correspond to harmful exposure potential via the consumption of contaminated fish as explained above. The regulatory framework for mercury in sediment is based on the California Human Health Screening Level (CHHSL) criteria.

CHHSLs are set by OEHHA for chemicals in soil. They are used as an advisory threshold under which levels are considered safe for exposure and human health. Specifically, the threshold is that there is less than a one-in-a-million cancer risk for humans. CHHSL advisories are published as reference values for residential soils, commercial soils and industrial soils, each of which use a less conservative exposure scenario respectively. The CHHSL for mercury in residential soil is the most conservative value for safe exposure and consists of a value of 18 mg/kg (18 ppm).

The CHHSL criteria constitute the current regulatory guidelines used by the gravel mining industry in the execution of gravel and sediment removal operations in mercury-impacted waterways of the Sierra Nevada. As a point of comparison, the conservative CHHSL for mercury in residential soil value is more than 30 times higher than the mercury concentration found in the sediment of Englebright Lake which research indicates has a maximum value of 0.5 mg/kg (0.5 ppm).

Englebright Lake is located downstream of numerous known hydraulic mines and mine features and was in fact constructed on the main stem of the Yuba River in the 1940s for the sole purpose of holding back mining debris. The suspension of the Englebright sediment into the water column would likely exceed common water quality criteria for mercury (50 ng/l). The water quality criterion for mercury is conservative compared to the CHHSL criteria for mercury in soil because mercury can methylate in the aquatic environment and enter the food web resulting in high levels in fish that people may eat. In fact, Englebright has a fish consumption advisory for mercury for multiple species of fish including black bass, sunfish, and rainbow trout. The fact that mercury in soil from Englebright, once it is out of the aquatic environment, may not pose a problem for human exposure points to the efficacy of a removal strategy for sediment in the dry. Removal in the dry prevents mercury from entering the aquatic environment where it can become bioavailable and biomagnify and bioaccumulate.

Conceptual Models

The Big Picture: Mercury from Sierra to Sea

At the height of the Gold Rush, gold mining was the primary use of mercury in the United States (Wiener and Suchanek, 2008). In contrast to the Eastern United States, where mercury contamination of surface water is associated with coal-based energy generation, in California, past gold and mercury mining activities are the primary source of mercury in aquatic ecosystems (Lim et al., 2013; Domagalski, 2001; Davis et al., 2008). Within the state of California, numerous abandoned mine sites continue to release mercury and mercury contaminated sediment in the present day (Wentz et al., 2014; Wiener and Suchanek, 2008; CDOC, 2000). There are hundreds of mines, mine features (including tunnels, adits, tailing sites, and debris control dams), and sediment deposits in watersheds that have yet to be cleaned up (Davis et al., 2008). Many of California's lakes, rivers, and reservoirs are impacted by mercury, and many water bodies with fish consumption advisories are in mining-impacted systems (Lim et al., 2013; Wiener and Suchanek, 2008). A positive correlation between mercury bioaccumulation in aquatic ecosystems and the intensity of hydraulic gravel mining has been documented in the Sierra Nevada (Hunerlach et al., 1999; May et al., 2000; Alpers et al., 2016).

Due to the large amounts of mercury contaminating these areas, costly remediation will likely be necessary to curtail fish contamination into the future (Wentz et al., 2014). In order to prevent fish contamination, existing mercury-contaminated sediment needs to be removed from aquatic ecosystems and additional contaminated sediment needs to be prevented from entering aquatic ecosystems. Mercury must be addressed at the source (hydraulic mines and mine features) and in water bodies where it is transported and deposited (such as reservoirs and the Bay-Delta).

The downstream transport of legacy mining contaminants impacts California water bodies from the summit to the sea (Davis et al., 2008; Wentz et al., 2014). Numerous studies have identified upstream sources - hydraulic mines and their features - to be the primary contributors of inorganic mercury to downstream reservoirs and the Bay-Delta (Saiki et al. 2009; Foe et al. 2008). Furthermore, historical mercury inputs may be the source for a generation of new methylmercury in these downstream waterbodies (Wentz et al., 2014). Inorganic mercury reduction was a major focus of the Bay-Delta Mercury Strategy Synthesis (2003 and updated 2018) which addresses the importance of source control to the Delta (Wiener et al., 2003).

Workshops for the Mercury Strategy Synthesis convened by the Delta Conservancy in 2016 identified that no environmental cleanup for mercury in the San Francisco Bay-Delta ecosystem would be successful without upstream source control. Due to mercury contributions from mines, the SWRCB specifically cites mine clean-up projects including the removal of contaminated sediment from behind reservoir dams as an important and necessary land management action for addressing mercury contamination both in the Sierra Nevada headwaters and the Bay-Delta (Davis et al., 2008). See Figure 6, for a conceptual model of the fate and transport of mercury from Sierra Nevada headwaters to the Bay-Delta.

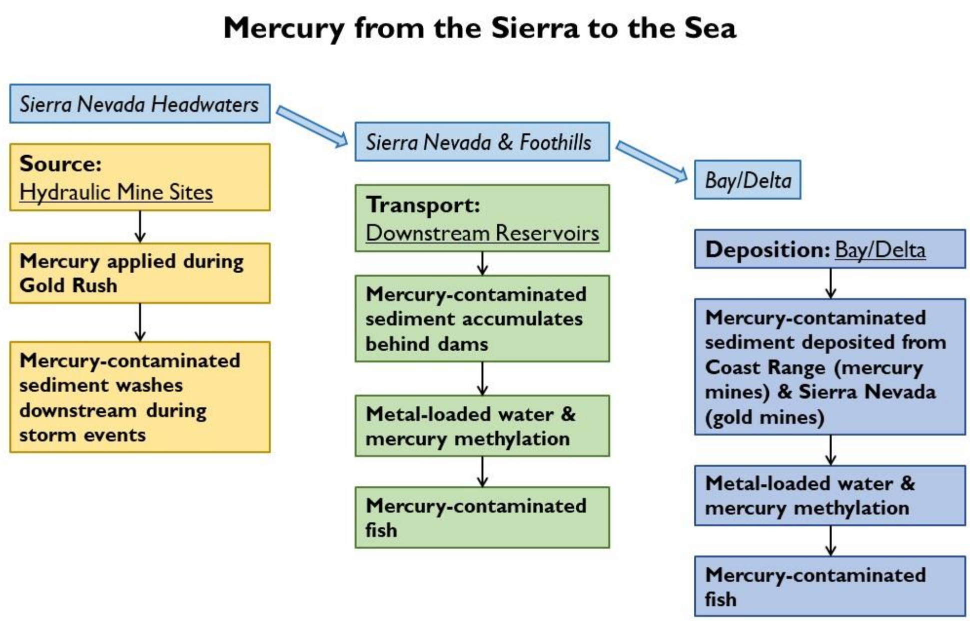

Figure 6: ***Mercury from the Sierra to the Sea***
Conceptual model of the scope and impact of mercury contamination in California. Figure Source: The Sierra Fund.

In Northern California, contamination is exceptionally persistent and substantial loads of mercury are still moving downstream toward the Bay-Delta (Davis et al., 2008). The overwhelming impact of mine debris flooding down from the Sierra Nevada hydraulic mines were the basis of the first environmental litigation in the United States, commonly referred to as the “Sawyer Decision” in 1884 (Alpers et al., 2005; CDOC, 2000).

Historical records indicate that by 1867, hydraulic mine debris had accumulated to as much as 70-ft thick in the Bear River drainage, creating significant flooding and navigation issues in the vicinity of the Feather and Sacramento rivers confluence (Hunerlach et al., 1999). Estimates for the Bear River indicate that 254 million cubic yards of gravel and sediment were added due to hydraulic mine operations, and of this approximately 139 million cubic yards of hydraulic mine debris persist in the lower Bear River (Hunerlach et al., 1999). Similar analysis of sediment transport in the North and Middle Forks of the American River found that approximately 213 million cubic yards of hydraulic mining sediment once filled the channel of the North Fork American River (Tetra Tech, 2007).

Over time the sediment stored in Sierra Nevada watersheds moves downstream, often becoming remobilized during major storm or flood events (Hunerlach et al., 1999; Davis et al., 2008). Mercury can be remobilized with the sediment. For example, USGS found total mercury concentrations in bed sediment of up to 26,000 ppm downstream of placer gold operations in the Sierra Nevada (Wentz et al., 2014).

Mercury Sources: Hydraulic Mines and Mine Features

Mercury Fate and Transport: Despite the fact that hydraulic mining ceased in 1884, and many debris control dams were built to hold back the tailings, there is a significant amount of inorganic mercury still coming from legacy hydraulic mine sites, especially during high flows (Fleck et al., 2011; Monohan, 2015). Hydraulic mine sites are characterized by denuded landscapes where the gold-bearing gravels were "power-washed" using large water cannons (hydraulic monitors). Inorganic mercury adsorbed to fine silts and clays eroding from these landscapes are suspended during storm events and transported from hydraulic mine sites and can lead to significant sediment and mercury loads (Fleck et al., 2011; Hunerlach et al., 1999).

Malakoff Diggins in the South Yuba River watershed was operated by the North Bloomfield Company and was in fact the subject of the "Sawyer Decision." This 300-acre un-remediated pit, now operated as a State Historic Park, discharges an estimated 100 g/year of particulate bound mercury and an estimated 500,000 kg of suspended sediment/year (Monohan, 2015). The loads of inorganic mercury being discharged from other hydraulic mine sites in CABY region watersheds are largely unknown. The debris control dams that were constructed to hold hydraulic mine debris upstream of the Central Valley farms are of unknown structural stability and the material they are holding back is likely contaminated with mercury (James, 2005). The extent to which debris control dams are emitting mercury contaminated discharge is largely unknown. Furthermore, terraces of hydraulic mining debris along river corridors likely continue to release unknown quantities of mercury.

In 2000, the California Department of Conservation estimated that there were over 40,000 abandoned mines in the state of California (CDOC, 2000). However, this number has never been groundtruthed, and it is based on the number of topographically occurring mine symbols on the United States Geological Survey (USGS) quadrangles, for which there may be many mine features denoted that are all associated with a single mine.

The Yuba and Bear River watersheds were among the most intensively mined watersheds in the Sierra and have some of the region's highest fish mercury concentrations (May et al., 2000). Both hard rock and hydraulic mines used mercury for gold processing, however, the stamp mill operations associated with hard rock mines had higher recovery rates and thus less mercury loss is attributed to hard rock mines as compared to hydraulic mines (Alpers et al., 2005).

The majority of hydraulic mines in the Bear and Yuba watersheds are on United States Forest Service (USFS) lands (CDOC, 2000). The USFS has the expertise and the jurisdiction to remediate mine sites, but no strategy to accomplish this. A hydraulic mines layer created by USGS delineates some of the hydraulic mines in the Sierra Nevada. A preliminary GIS analysis of the number of hydraulic mines on USFS lands in the Yuba and Bear River watersheds indicates that there are 30 hydraulic mines in the North Yuba (1,800 acres), 18 hydraulic mines in the Middle Yuba (570 acres), 14 hydraulic mines in the South Yuba (890 acres), 6 hydraulic mines in Deer Creek (130 acres) and 13 hydraulic mines in the Bear River (525 acres). There were as many as 48 dams of various types constructed in these basins over time, but most were ephemeral and few remain. However, low inset terraces of hydraulic mine debris created by sedimentary deposits behind these dams may remain where they once stood and may be mobilized during major storm events, releasing contaminated material into watersheds (James, 2005).

Abandoned hydraulic mine sites and mine features are sources of mercury-contaminated sediment to downstream watersheds. See Figure 7. Sediments are insoluble products of earth materials released from the landscape due to weathering and biological activities (Campbell et al., 1988). In general, many trace metals associate with sediment by metal-solid interaction and the bioavailability of the metal depends upon the nature of metal-solid interaction (Zhong and Wang, 2006). Compositions of sediment define the nature of metal-solid interaction. Organic matter in sediment works as a sorption-bridge to bind Hg to sediment (Xu and Allard, 1991). Organic matter in sediment is the key to binding particulate mercury (PHg) with sediment (Winch et al., 2008). The study of soil samples at the El Terronal mine site (Mieres, Spain) indicates that the bioavailability of PHg in sediment from gold and mercury mines increases directly with distance during redistribution and mobilization (Fernandez-Martinez et al., 2005). This occurs not only due to break down of the organic bonds between sediment and Hg, but also due to the weathering process during transport (Fernandez-Martinez et al., 2005).

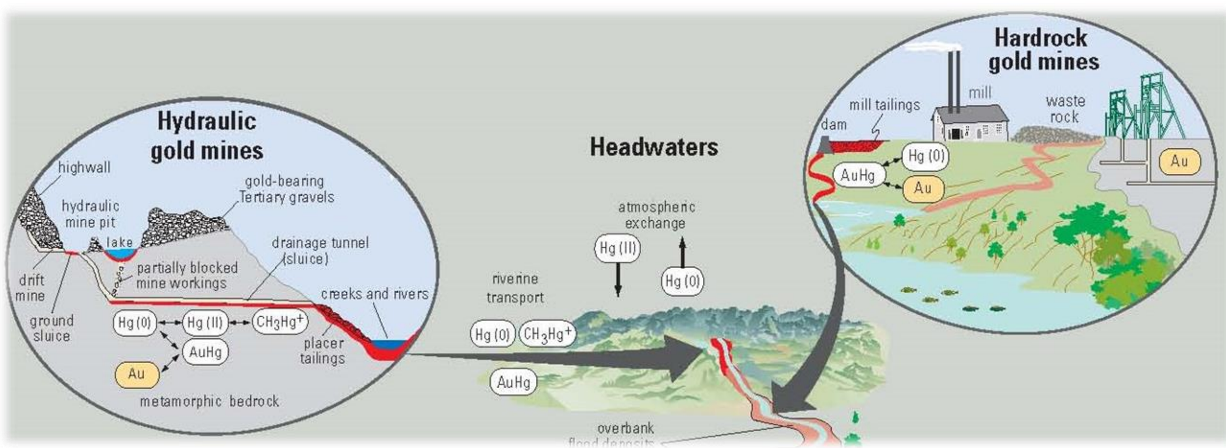

Figure 7: *Mines as Sources of Mercury*
Drainage from hydraulic and hard rock mines are sources of mercury to California's headwaters. Figure Source: excerpt from USGS Fact Sheet 2005_3014_v1.1.

The processes by which legacy mercury at hydraulic mines sites in the Sierra Nevada can be mobilized, transported and methylated was explored in a 2007-2008 study conducted by USGS at the confluence of Humbug Creek and South Yuba River (Fleck et al., 2011). See Page 23, Figure 8. USGS investigated the potential impacts of suction dredging for gold recovery on mercury transport, methylation, and bioaccumulation of mercury from a hydraulic mining debris deposit.

Water samples collected before, during, and after suction dredging were analyzed for total suspended solids, filterable total mercury (THg), particulate-bound total mercury (PHg), and methylmercury (MeHg) (Fleck et al., 2011). These samples were used to quantify the different forms of mercury coming from hydraulic mine debris that was dredged.

In addition, samples of unconsolidated material were taken from, in, and around the South Yuba River and were run through a series of laboratory tests. The laboratory tests included (1) placing them under varying oxidation-reduction conditions to simulate riverine transport and (2) mixing with other sediments to simulate sediment deposition to evaluate potential MeHg formation in downstream environments including Englebright Lake and the Sacramento-San Joaquin Delta (Marvin-DiPasquale et al., 2011). Simply put, these tests were to see if the mercury coming from the hydraulic mine debris could be methylated under different conditions.

Figure 8: *Mine Impacts to the South Yuba River*
Hydraulic mine debris erodes into the South Yuba River (SYR) at the confluence of Humbug Creek (Left). The SYR is a Wild and Scenic designated river, and locations like the Edwards Crossing Bridge (Right) are popular year-round among recreationists. Photo Source: Alex Keeble-Toll.

Two primary findings were produced by the Humbug Creek research:

1. Mercury is primarily transported from the hydraulic mine site as bound to particulate fine silts and clays (< 0.063 mm) during winter storms.

2. Mercury can stay in suspension for a long time and can therefore be transported long distances from source areas and it can be methylated.

Mercury in Forest and Land Management

Legacy mines and the early forestry activities that accompanied the Gold Rush have resulted in denuded landscapes, even-aged forests, and the widespread distribution of mercury across the landscape. Though fire-fighting agencies are increasingly recognizing the risk associated with combatting wildfires on abandoned mine lands, including the potential for bodily harm from unmarked physical hazards and potential exposure to toxic volatilization of mercury, mine remediation activities have yet to be integrated holistically into forest management strategies such as fuels reduction.

Climate change in the Sierra Nevada will increase the risk of catastrophic wildfire as warmer temperatures and consequent drier conditions result in longer fire seasons and more pests and disease in the forests (Sierra Nevada Conservancy (SNC), 2014). Unhealthy forests and loss of forest to catastrophic wildfire reduces retention of precipitation, resulting in higher rates of run-off and less groundwater recharge. The effect of wildfire on forest hydrology is complicated by mine-impacted lands with elevated erosion rates in the region. Post-fire erosion will likely increase the amount of particulate mercury (PHg) transported with sediment into aquatic ecosystems. Forest fires that occur in hydrologic paths on mine sites and between the mines and streams and rivers are especially problematic because loss of the buffer capacity (flow attenuation, soil health, and water retention ability) of the forest.

It is important to note that mines were developed with the use of water and water ways in mind. In other words, water ways were often used to convey debris away from mine site and many mines were either along streams or had tunnels that transported material to streams, further increasing the impact to riparian areas and sediment load transport. See page 25, Figure 9.

Sediment and Erosion: Soil type, vegetative cover, organic floor matter, and canopy cover play direct roles in erosion before and after a fire, as well as the severity of the burn (Williams and Melack, 1997). Major factors in determining the severity of the burn include the quality and quantity of fuels, the properties of the soils, the topography of the area, the climate, and the weather (Elliott, et al., 2006). The presence of ground litter adds fuel to the fire, allowing for a higher temperature burn. Wildfire removal of ground litter and the physical alteration of soil properties make the ground highly susceptible to erosion post-fire, as evidenced by increased erosion rates of at least two to three orders of magnitude higher post-fire (Moody and Martin 2001; Long et al. 2014). High severity fires have the ability to create hydrophobic properties in the soil through collapsing the soil structure which reduces porosity, and increases water repellency (MacDonald and Huffman, 2004).

Figure 9: ***Lowell Fire, Nevada County***
The 2015 Lowell Fire in Nevada County burned over 2000 acres of steep terrain with numerous hydraulic mines in the drainage(s) above Rollins Reservoir. Note the light-colored sparsely vegetated hilltop and slope areas representing hydraulic mine sites. Figure Source: Yuba Net, 2015.

Erosion Mitigation: Thinning of the forest can mitigate the effect of wildfire by decreasing the amount of fuel available. Woody by-products can be masticated and spread over the site to reduce erosion. Quantifying the efficacy of integrated forest management projects builds regional capacity to design and implement forest management projects that reduce erosion, benefiting ecosystem and watershed health. Acreage reduction in surface fuels (vegetation and downed woody material), ladder fuels (plant matter that helps fire spread from ground into tree canopy), and an overall reduction in biomass reduces the risk of high severity fires.

Mastication in the forest and near waterways, whereby organic matter is broken into smaller pieces through grinding, shredding, or chopping and then left scattered on site, can help to increase water infiltration, and to decrease surface water runoff and erosion (Southwest Fire Science Consortium, 2013; Long et al. 2014). There are two predominant methods for managing pre-fire sediment delivery to fluvial systems, both related to organics, and these methods can be implemented stepwise to achieve success: (1) the removal of ground and/or low-ladder fuel(s), and (2) the breaking down (mastication) of organic material(s).

Frequent and thorough mastication is most successful as it aids in water retention, as well as fire suppression. In the Lake Tahoe region, it was found that erosion increased as mastication cover decreased (Stubblefield et al., 2007). More specifically, analysis indicated that ground without any cover experienced 97% more erosion than plots with 25-50% mastication cover (Stubblefield et al., 2007). This may demonstrate that even small amounts of ground litter have a great ability to retain sediment, decrease erosion, and ultimately decrease the sediment delivery to streams. At denuded hydraulic mine sites the application of forestry by-products can help to rebuild soil and consequently promote stabilizing vegetation, reducing contaminant and sediment transport into water bodies.

Other activities to manage the erosion potential for mercury-contaminated sediment include efforts to restore stable drainage networks and stabilizing headcuts to reduce active erosion. Diverting runoff away from contaminated mine materials can help to retain contaminants on-site, and this can be facilitated significantly by using mastication or other methods to promote revegetation. Remediation techniques, including the application of woodchips are being explored on USFS lands (for example at the Alpha Diggins on TNF and at the Walker Mine on PNF) for their effectiveness in reducing sediment and contaminant transport. If the efficacy of these methods can be demonstrated, they represent especially attractive forest management strategies due to the potential for sustainable re-use of forestry materials that may already exist on site.

Forest management projects that require a Timber Harvest Plan (THP) or receive grant funds from the Greenhouse Gas Reduction Fund (GGRF) are required to report changes in biomass and carbon equivalent. USFS fuel reduction in the state generally does not require a THP and thus there is a lack of information on this metric. Quantification of biomass provides information that leads to better understanding of the extent to which treatment levels are improving forest health (Bustic et al., 2017). Furthermore, in the context of leveraging forestry byproducts for erosion control and mine remediation activities, quantifying biomass reuse may help to quantify and benefits this approach.

Contaminant Mitigation: Biochar, or pyrolyzed biomass, is emerging as a passive forest management technology that has potential for strategic integration into post-fire recovery regimes for landscapes catastrophically impacted by wildfire. Biochar is formed through the combustion of biological residues at low oxygen levels, which results in porous, low density, carbon rich material (Beesley et al., 2011). Biochar acts as a soil conditioner, enhancing plant growth by supplying and retaining nutrients and by improving the physical, chemical, and biological properties of the soil (Fellet et al., 2011).

In mine-impacted regions like the Sierra Nevada, biochar has application potential due to its capacity to significantly decrease the bioavailability of mine contaminants including Hg, Ni, Fe, Cd, Pb, and Zn (Fellet et al., 2011). Furthermore, biochar has been shown to reduce contaminant transport by promoting the formation of aggregates that increase water retention capacity, thus limiting runoff (Fellet et al., 2011; Beesley et al., 2011). In denuded landscapes biochar application can help to rebuild soil and consequently promote stabilizing vegetation, another strategy for reducing contaminant and sediment transport into water bodies.

The research on erosion following mega fires substantiates the following findings for fires in mine impacted areas:

1. Fuels treatment to reduce the severity of fire will reduce sediment and mercury loading.

2. Stabilization of denuded areas and erosive material on mine sites, using wood chips, masticated material, and/or biochar, will reduce the sediment and mercury loads to streams and rivers.

3. Riparian area buffering capacity improves water infiltration and the retention of fine silts and clays reducing sediment and mercury loads to streams and rivers.

Mercury-Contaminated Sediment in Reservoirs

Methylation, Biomagnification, and Bioaccumulation: Reservoirs play an important role in the fate of mercury in Sierra Nevada watersheds. Sampling of aquatic biota above and below selected foothill reservoirs, indicates that reservoirs act as trap for both sediment-associated inorganic mercury and biologically available organic mercury (Saiki et al., 2009). In anoxic environments mercury in sediment may be transformed by sulfate or iron reducing bacteria to the more toxic and bioavailable organic form, methylmercury (Domagalski, 2001; Lim et al., 2013). The oxygen-poor benthic environments of reservoirs are associated with conditions amenable for the methylation of elemental mercury (SWRCB, 2013). See Figure10.

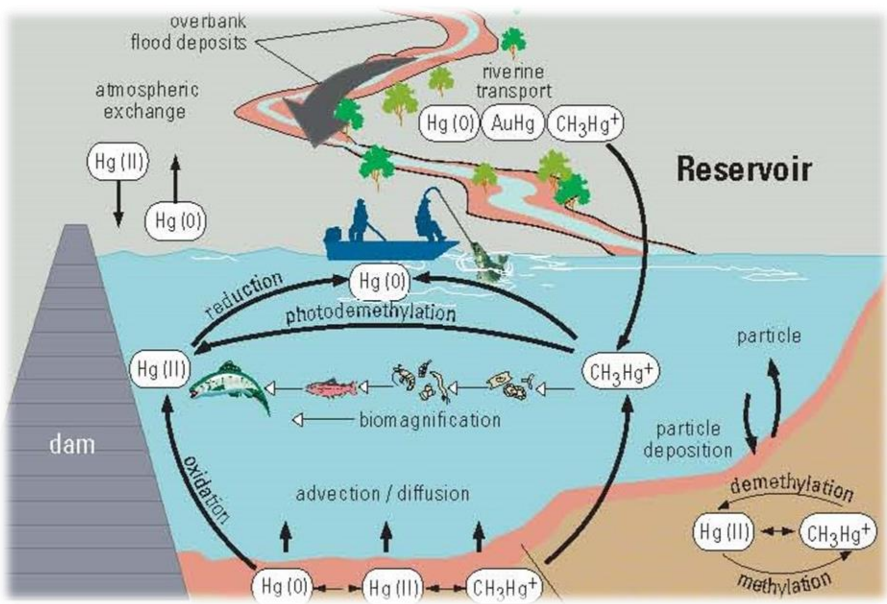

Figure 10: ***Mercury Cycling in Reservoirs***
Low oxygen conditions, such as those often found in reservoirs, are associated with mercury methylation. Figure Source: excerpt from USGS Fact Sheet 2005_3014_v1.1.

Methylmercury (MeHg) enters the food web through phytoplankton and zooplankton (Boudou and Ribeyre, 1997). MeHg is retained and biomagnified in aquatic food webs and thus contamination levels typically increase by trophic level with top predatory fish generally exhibiting the highest mercury concentrations. (Boudou and Ribeyre, 1997). The largest biomagnification of methylmercury in the aquatic food web occurs at the trophic step between water and algae (Wentz et al., 2014). USGS studies conducted nationwide during 2002-2009 estimated the increase to be a magnification of approximately 10,000 times (Wentz et al., 2014). At each subsequent trophic level transfer (macroinvertebrates; small fish; predatory fish) the biomagnification has been estimated to occur at a rate of 2-5 times (SWRCB, 2010). Increases in mercury from invertebrates to top predators have been estimated to be approximately 100 times (Wentz et al., 2014). The USGS has estimated that as a result of bioaccumulation, methylmercury concentrations can increase over 1 million times from water to top predator fish (Wentz et al., 2014).

Older high trophic level fish that have spent a lifetime consuming and thus bioaccumulating mercury typically have high levels of mercury due to the fact that levels of mercury in fish depend on food source, lifespan, and trophic level (Herger and Edmond, 2012). See Figure 11. As a result, smaller, younger fish typically have lower levels of bioaccumulative contaminants including mercury (Scherer et al., 2008). These factors help to explain why upper-trophic-level species (largemouth bass, *Micropterus salmoides*; smallmouth bass, *M. dolomieui*; and spotted bass, *M. punctatus*) that are both long-lived and predatory are associated with high levels of mercury (>1 ppm). This relationship does not always exist, however, and may be impacted by slow growth rates, fish that are flexible foragers, and fish that change their dietary preferences with stages in development (Davis et al., 2008). For example, some change in fish tissue mercury level over the lifetime of fish is attributed to ontogenetic shifts in diet, such as that observed in brown trout (*Salmo trutta*), that initially feed on small lower-trophic-level invertebrates but switch to large higher-trophic-level fish as adults (Saiki et al., 2009).

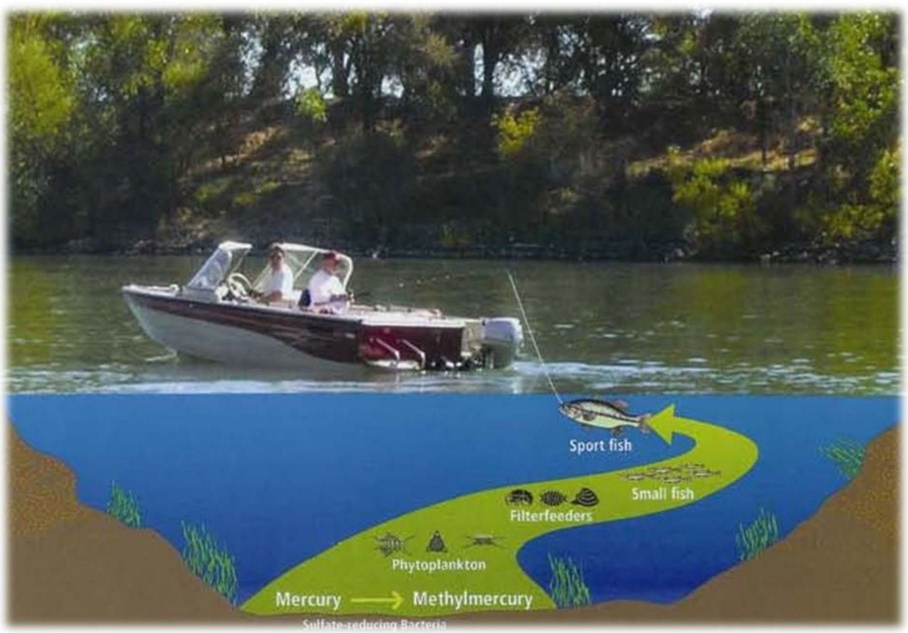

Figure 11: *Mercury and Trophic Level*
Upper trophic level "sportfish" such as black bass are typically associated with higher levels of mercury than small fish such as sunfish. Figure Source: San Francisco Estuary Institute, *The Fish Mercury Project*.

USGS research conducted at Camp Far West Reservoir has established the importance of the aquatic food web and mercury methylation in a reservoir contaminated by mercury from historical gold mining. Camp Far West, is located downstream of Rollins Reservoir and Lake Combie on the Bear River and the primary source of Hg is believed to be contaminated mine sediments transported from upstream reaches of the Bear River during high-flow events (Saiki et al., 2009). During 2002-04, the USGS studied mercury cycling in Camp Far West, sampling water, bed sediment, and zooplankton quarterly at several locations within the reservoir, and fish (treadfin shad, bluegill, and spotted bass) annually (Alpers et al., 2008; Stewart et al., 2008;

Saiki et al., 2009). This study identified the benthic and pelagic pathways by which mercury enters the food web and the biomagnification and bioaccumulation of mercury in the food web leading to fish tissue mercury levels at the reservoir that are harmful to human health and upon which a site-specific fish consumption advisory is based. The research at Camp Far West substantiates the following findings:

1. Mercury methylation typically occurs most efficiently during warm summer months in anoxic zones that establish in reservoirs below their surface mixed layers and/or in the shallow groundwater tables.

2. Particulate bound mercury can be methylated when sulfate-reducing and/or iron-reducing bacteria are allowed to develop in low-flow, anoxic conditions.

Mercury Exposure via Fish Consumption

Mercury Exposure: Fish consumption represents the primary pathway of human exposure to mercury in most populations (Carrasco et al., 2011; Engelberth et al., 2013; Lepak et al., 2009; May et al. 2000; Wiener and Suchanek, 2008). This makes representative fish tissue data essential for assessing exposure risk and clear communication of this information critical for reducing exposure. In the United States mercury contamination is the reason behind the vast majority of fish and wildlife consumption advisories (Wentz et al., 2014; Wiener and Suchanek, 2008). In 2006, mercury was responsible for 80%, or 3,080, of all fish consumption advisories posted in the U.S. (Wiener and Suchanek, 2008). According to OEHHA, mercury is the driver behind 97% of fish advisories in California.

Mercury is a developmental neurotoxin with human health impacts that are numerous and well-documented (Adams and Denton, 2008; OEHHA, 2008; Lepak et al., 2009; Lim et al., 2013; Wentz et al., 2014; Wiener and Suchanek, 2008). Exposure to even low levels of mercury is linked to adverse outcomes that can include damage to the brain, nervous system, kidneys, immune system, and cardiovascular health (Engelberth et al., 2013; Stern and Korn, 2011). Methylmercury exposure is especially dangerous for pregnant women because the compound easily passes through the placenta and the blood-brain barrier (Adams and Denton, 2008). The effects of low-level mercury exposure most frequently cited are neurological impacts on fetuses during the third trimester (Wentz et al., 2014). Children whose nervous systems are still developing are also considered sensitive populations for mercury exposure (OEHHA, 2008; Lepak et al., 2009; Lim et al., 2013; Wiener and Suchanek, 2008). As such, concerns about methylmercury exposure tend to focus on the potential for neurotoxicity during fetal and early childhood development (Lepak et al., 2009; Wiener and Suchanek, 2008).

Fish Consumption Advisories: One public health strategy to reduce mercury exposure is to create fish consumption advisories. See Page 30, Figure 12. Fish consumption advisories delineate parameters for the safe consumption of fish based on species, demographic group, and the recommended maximum number of meals of mercury contaminated fish species that can safely be eaten per week or month. Advisories can be leveraged as a mercury management tool because adverse health consequences may be averted through education, thus avoiding potentially large clean-up costs (Jakus et al., 1998). However, this approach is not failsafe because advisories are "voluntary recommendations" regarding fish consumption and are not specifically regulatory (Scherer et al., 2008). Furthermore, some research suggests that even where advice is posted it may not have the intended impact due to the fact that fish consumers are not necessarily knowledgeable about risk messaging, advisory rationale, or health risks (Beehler et al., 2003). In addition to women of child-bearing age and children, other at-risk populations include Native Americans, anglers, and ethnic minorities. These groups are known to have rates of fish consumption much higher than that of the general United States population, making them more vulnerable to exposure (Judd et al., 2015). The USEPA recommends assuming a 99th percentile rate of consumption for these groups instead of the 90th percentile rate considered protective of the general population (Shilling et al., 2014).

Figure 12: ***Posting of Fish Consumption Advisories***
The California Office of Environmental Health Hazard Assessment (OEHHA) issues fish consumption advisories (Left), however, water managers are not required to post this information (Right). Figure Source: OEHHA, https://oehha.ca.gov/fish/advisories. Photo Source: The Sierra Fund Archives.

In recent years the State has recognized that the inability of California Native American tribes to safely consume fish in historic quantities due to mercury contamination may constitute a Clean Water Act violation because these populations are being prevented from taking full advantage of designated beneficial use-values of local water bodies (Shilling et al., 2014). To address this, in July 2017 the USEPA approved the SWRCB's new water quality objectives that set limits on mercury levels in fish that are responsive to Tribal and subsistence uses.

Angler Surveys: Understanding angler catch and consumption patterns provides key information about the exposure risk associated with specific water bodies. See Page 31, Figure 13. This information can be used to develop appropriate fish consumption advice based on species that are caught and consumed in a given region. Furthermore, surveys can provide insight into angler understanding of risk and reveal important avenues for the dissemination of public health information (Judd et al., 2015; Shilling et al., 2010; Monohan, 2011; Monohan and Keeble-Toll, 2018).

Figure 13: *Angler Surveys in the Gold Country*
An angler is surveyed at Lake Clementine (Left) by staff of The Sierra Fund as part of the *Gold Country Angler Survey: 2018 Update*. The catch consists of black bass and carp, both known to be high in mercury (Right). Photo Source: The Sierra Fund Archives.

There are three basic survey types used in most fish consumption studies, 24-hour recall surveys, food frequency questionnaires and creel surveys. 24-hour recall surveys are considered more accurate as respondents are able to articulate consumption that occurred in a short timeframe, however they lack the detail required to construct an exposure rate across time. Food frequency questionnaires are useful for characterizing both daily variation at the individual level and seasonal variation at the population level (Judd et al., 2015). The third type of angler survey that is commonly used is a creel survey where anglers are interviewed in the field as they are fishing and asked to show their catch (Judd et al., 2015).

In 2009-10 The Sierra Fund surveyed 151 anglers at water bodies in the Yuba and Bear watersheds as part of the *Gold Country Angler Survey* (Monohan, 2011). See https://www.sierrafund.org/angler-survey/. This effort was doubled in 2015-2017 in order to increase the amount of sociodemographic data about anglers who fish in the Cosumnes, American, Bear, Yuba (CABY) watershed region so that this information can be used to inform priority actions to reduce human exposure to mercury. The second round of surveys both increased the overall dataset and provided a method for evaluating the potential public health benefit of a key project of TSF, the Post It Day project to post state-issued fish consumption advisories at Sierra Nevada waterbodies. See https://www.sierrafund.org/2017-advisory-posting-protocol/.

To promote consistency and facilitate the cross-regional comparison of results, the survey used was based on the Sacramento River Angler Survey, which has been administered widely in the Sacramento-San Joaquin Delta. The Sacramento River Angler Survey is a food frequency (FFQ) questionnaire developed by the University of California, Davis in collaboration with the California Department of Public Health. The researchers behind the development of this survey contend, "the vast majority of comparable studies using FFQs have reported accurate findings using this approach among a wide range of nationalities and ethnicities" (Shilling et al., 2010, p. 335).

Surveys were administered by individuals trained per the guidelines of the Healthy Fish Coalition at 15 waterbodies in the Sierra. In 2009 and 2010 volunteers conducted surveys; in 2015-2017 the Sierra Native Alliance (SNA) Native Youth Conservations Corps (NYCP) conducted surveys. The majority of the interviews took place at Camp Far West Reservoir (n=67), Rollins Reservoir (n=63), Upper Scotts Flat Reservoir (n=61), Lake Englebright (n=61), and New Bullards Bar=43), Catch and consumption patterns, mercury exposure potential, and the capacity of anglers to assess risk was determined based on responses to a standard interview. Differences in angler attitudes and behaviors about locally caught fish before and after advisories were posted were queried with questions added to the survey in 2015.

Across all locations the most popular fish species eaten were trout (rainbow and brown), catfish, kokanee salmon, and bass (largemouth, smallmouth and striped). Bass and large brown trout are predatory fish and data used by OEHHA to develop advisories indicate that these species often contain levels of mercury precluding unlimited consumption by all population groups. The Statewide Advisory for Lakes and Reservoirs Without Site-Specific Advice and numerous site-specific advisories for Sierra Nevada waterbodies recommend that women of child-bearing age (18-49 years) and children (1-17 years) should avoid eating these species.

Of those surveyed, 55% reported eating fish that were caught by themselves or by someone they know and 35% who eat what they catch also feed it to their children. Nearly half of anglers reported feeding their catch to women of child bearing age (46%) and a small number of respondents also feed locally caught fish to pregnant or nursing women (8%). Pregnant women, infants, and children are sensitive population groups for mercury exposure because mercury impacts are the most significant on developing nervous and immune systems.

Overall, 81% of respondents reported that they had seen or heard health warnings about eating fish. However, when asked to provide details about the health warning, 12% of anglers could not accurately recall the warning at all, 56% had some level of awareness, 24% could correctly recall one aspect of the warning, 7% could recall two aspects of the warning, and only 1% of respondents could correctly recall three aspects. In other words, only 1% of surveyed anglers could articulate information about species, population group, and frequency of consumption. The data indicate little increase in the number of anglers reporting that they had seen or heard health warnings about fish across the time-period (2009-2017), however, after fish advisories were posted there was an almost two-fold increase in the number of anglers able to articulate information about one issue (from 13% to 24%).

Having access to healthy eating guidelines communicated by OEHHA fish advisories may reduce mercury exposure as many anglers consume their catch and feed it to others. Equally important is that anglers understand and are able to use this information.

To summarize, findings from this research include:

1. Posting OEHHA's advisory signs at publicly accessible fishing locations increases the likelihood that anglers are aware of health warnings about eating fish

2. It may be necessary to conduct additional outreach and education to ensure that anglers understand the information contained in fish advisories and are able to take action to protect their health.

THE STRATEGY

Strategic Target 1: Hydraulic Mines and Mine Features

Background

Mineral extraction has been a significant economic and physical force in the Sierra Nevada for over 160 years. United States Forest Service's Tahoe National Forest (TNF) is estimated to have some of the most extensive gold deposits and mining history in the nation, with more mining claims within its forest boundary than any other National Forest (United States Department of Agriculture (USDA), 2011). Of watersheds located in the northwestern Sierra Nevada, the Bear and South Yuba Rivers are associated with the most intensive hydraulic mining and highest average levels of mercury bioaccumulation in aquatic species (Alpers et al., 2005; May et al., 2000). The South Yuba River flows into the main stem of the Yuba River at Englebright Dam and is a state-designated Wild and Scenic River. The Yuba and Bear Rivers are major tributaries of the Feather River, which flows into the lower Sacramento River Basin and ultimately the San Francisco Bay-Delta. Due to the high levels of mercury contamination documented in the Yuba and Bear watersheds and the connectivity with the Bay-Delta, these watersheds have been selected as areas of focus for the HMSR Strategy. This does not preclude Strategy outcomes from being applicable to other impacted watersheds including the Feather and the American.

Scope

By focusing on mercury contamination from hydraulic mines and mine features on TNF land in the Yuba and Bear watersheds HMSR Strategy has a scope that is manageable and meaningful. Not only is the number of mine features selected for analysis in the hundreds (not thousands), this project aims to reduce a single contaminant, mercury. By targeting the mercury contamination associated with hydraulic mines across a single landownership (USFS) it is possible to have standardized and measurable outcomes. The baseline monitoring (water quality and sediment and mercury loads) and remediation methodology (sediment and erosion control) for hydraulic mines and their features generated as part of this Strategy accomplishes the necessary planning needed for implementation of effective remediation projects by the landowner.

Strategy for Remediating Mercury Sources: Hydraulic Mines and Mine Features

Develop and apply best available technologies (BATs) and methods to prioritize and remediate mercury contamination sources in the headwaters.

This Strategy will be based on current scientific understanding of mercury fate and transport. The Strategy developed as part of this understanding will be integrated into Land and Water Management Plans for USFS and others.

Actions

Action 1: Develop inventory and database of hydraulic mine and mine features*. Create an inventory of hydraulic mine sites and their associated site features, including debris control dams, terraces of mining debris, tunnels, and pits located in the portions of the Yuba and Bear watersheds encompassed within TNF.*

The Hydraulic Mines and Mine Features Database will be an inventory of potential sources of mercury in the headwaters of the Yuba and Bear River watersheds. The TNF LiDAR data, satellite imagery, existing inventories and historic records will be used to identify hydraulic mine sites and mine features. The identified sites will be mapped using spatial analysis tools in Arc-GIS. The hydraulic mine pits, debris control dam deposits and in-channel terraces will be delineated manually. Existing hydraulic mine databases will be updated using LiDAR data. Additional LiDAR data are needed for the Plumas National Forest (PNF) which encompasses portions of the North Yuba Watershed. Geomorphometric characteristics will be measured for each feature using differences in actual and generated digital elevation models. In this way the volume of displaced and in place hydraulic mine debris will be estimated for each feature.

Action 2: Ground- truth features in the Hydraulic Mines and Mine Features Database*. Check the accuracy of remotely sensed data with site visits and collect baseline data for site prioritization efforts.*

The conditions and coverage of site features will be recorded using mobile data collection devices and a geographic data collection application. For example, the free, downloadable Avenza App can interface with Arc GIS on-line, making data entry after field visits a streamlined process. A similar system is currently being used by the California Department of Conservation (CDOC) to collect data about contamination and safety hazards at physical features associated with abandoned mines statewide.

Action 2a: Physical Hazards Inventory*. Ground-truthing includes physical hazards characterization of airshafts, adits, debris control dams (impoundments) and subsidence features for future assessment of the extent and stability of the features.*

The objective of the groundtruthing assessment is to determine the features that are present. See examples in Figure 14. Of particular interest are ponds, drain tunnels, storm water runoff, physical hazards and erosional features, which pose physical hazards and transport contaminants to water. By using the Avenza App and coordinating with other regional efforts, data will be compatible with the statewide Abandoned Mine Lands (AML) database.

Figure 14: *Tunnels Along Humbug Creek*
The Hiller Tunnel (Left), which drains to Diggins Creek a tributary to Humbug Creek, is a well-marked historic feature at Malakoff Diggins State Historic Park. The un-named and un-marked tunnel (Right) is along Humbug Creek near Relief Hill Road. Photo Source: Alex Keeble-Toll.

***Action 2b: Chemical Hazards Inventory**. Sample soil and water for contamination at hydraulic mine sites so that sites can be prioritized for more comprehensive assessment.*

Activities will include standard hydrologic and geochemical characterization methods used to assess mine-impacted landscapes. These activities consist of collection of streamflow data, storm water sampling, calculating loads for sediment and mercury, and characterizing deposits. Soil and water samples will be collected using Ultra Clean Hands techniques for trace metal sampling (USEPA, 1996). See Page 36, Figure 15.

Figure 15: *Water Quality Sampling*
Sampling runoff using the Ultra Clean Hands technique in the Malakoff Diggins hydraulic pit during a major storm event. Photo Source: The Sierra Fund Archives.

Sampling should be conducted under base flow and storm flow conditions, and include filtered and nonfiltered samples for metals such as Cu, Ni, Zi, Fe and Hg as well as temperature, dissolved oxygen, turbidity, total suspended solids, pH and electrical conductivity so that sites can be compared to each other and ranked according to their level of contamination. The level of contamination can be compared based on instantaneous loads, as well as the concentration of contamination in the suspended sediment.

***Action 3: Develop pilot projects and evaluate mine remediation treatments**. Mine remediation treatments of hydraulic mines typically includes diverting waterways around contaminated areas, re-contouring areas to reduce erosion of contaminated debris, and sloping back eroding banks.*

Sampling should be conducted before and after remediation in order to quantify the effectiveness of remediation activities in reducing sediment and mercury loads. An Effectiveness Monitoring Plan (EMP) will be developed to evaluate how successfully project activities reduce sediment and mercury transport. The EMP will include a Sampling and Analysis Protocol to ensure quality control. Monitoring protocols will ensure that project activities contribute to regional understanding of how to reduce mercury transport as part of forest management. Sediment and water will be collected using Ultra Clean Hands techniques for trace metal sampling (USEPA, 1996).

Action 4: Rank and prioritize hydraulic mines and mine features for remediation*. Develop criteria using the geospatial database and assessment data to select sites for remediation.*

Hydraulic mines and mine features can be ranked based on risk to human and ecological health, physical hazards, and the interconnectedness of features, such as hydraulic mine sites that drain into streams and rivers. The ranked features can be prioritized based on attributes such as: (1) level of contamination and potential for erosion; (2) proximity to threatened or endangered species habitat; (3) proximity to disadvantaged communities; (4) the projected benefit of remediation on watershed resiliency; (5) access to the sites; and (6) funding opportunities.

Action 5: Make recommendations and evaluate best practices for remediation*. Assess sites and features and make recommendations based on the results for remediation activities.*

Best practices for assessing, prioritizing and remediating hydraulic mines and mine features (mercury sources) will continue to be developed and modified based on the above actions and incorporated into this document annually to inform future efforts in the region. Current best practices for reducing mercury transport from hydraulic mine sites and mine features that contaminate downstream waterways include:

- **Reducing Contamination from Hydraulic Mines and Mine Features - Best Practice 1:** Minimize the erosion of contaminated materials: The erosion and release of silts and clays should be limited to reduce the downstream transport and incorporation of mercury into the food web.

- **Reducing Contamination from Hydraulic Mines and Mine Features - Best Practice 2:** Minimize the extent to which mercury-contaminated sediment comes in contact with water. Mercury methylation can occur in anoxic zones found in ponds and shallow groundwater. Standing water at mercury-impaired sites should be avoided and running water should be routed around areas of contamination.

Criteria for an activity to be designated a best-practice will continue to be developed by the HMSR-TAC. Best-practices are expected to evolve over time as additional methods and strategies are identified through pilot-scale implementation.

Outcome of Strategy Implementation for Hydraulic Mines and Mine Features

Remediated mines and mine features will reduce mercury contamination of downstream water bodies (including the Bay-Delta).

Strategy Implementation Evaluation Criteria

- One sub-watershed per year assessed in partnership with USFS, TNF.
- One hydraulic mine site remediated per year in partnership with USFS, TNF.
- Coordination of best practices into regional regulatory and planning efforts such as the Statewide Reservoir Mercury Total Maximum Daily Load (TMDL).

Current needs for the implementation of this strategic approach include LiDAR data for reaches of the Yuba and Bear River watersheds not in the Tahoe National Forest. This includes areas of the North Yuba watershed that are in the Plumas National Forest, and areas in the Yuba and Bear River watersheds that are downstream of the Tahoe National Forest boundary.

Strategic Target 2: Mercury in Forest and Land Management

Background

The Tahoe National Forest (TNF) is one of eighteen USFS National Forests in California. TNF includes both foothills on the western slope (Sierra Nevada Foothills Ecoregion, M261F) and the Sierra crest (Sierra Nevada Ecoregion, M261E). Due to unique climate conditions (wet, cool winters and warm, dry summers) TNF is considered to have some of the most productive forest lands in the United States (USDA, 2011).

Approximately 60% of California animal species call the Sierra Nevada home. The predominant natural communities of the region include mixed conifer, ponderosa pine, Jeffrey pine, white fir, red fir, lodgepole pine, huckleberry oak, western juniper, aspen, big sagebrush, mixed subalpine forest, mountain hemlock, and whitebark pine. The aspen and mountain alder series are common in riparian or wet areas, while shrub lands typically are composed of the bush chinquapin, greenleaf manzanita, huckleberry oak, and the mountain whitethorn series.

Legacy mines in the Sierra are a complicating factor for forest management. Hydraulic mines consist of altered landscapes where hilltops were excavated or exhumed to recover gold. Over the last 100 years these sites have typically partially vegetated with dense manzanita and madrone, leading to high fuel loading. Mercury used at hydraulic mine sites remains in the soils and can be transported into watersheds and downstream reservoirs. The effect of wildfire on watershed health in a region with numerous hydraulic mine sites and unprecedented fuel loads has resulted in sedimentation and volatilization events and unknown releases of mercury. Forest fires occurring in the hydrologic path between hydraulic mines sites and stream channels may result in swift and significant transport of sediment and mercury into vulnerable water bodies.

Scope

The scope of strategy implementation consists of forested lands that surround hydraulic mines in the forests of the Yuba and Bear River watersheds on TNF. See page 39, Figure 16. Pilot model fuels treatment will facilitate evaluation of the efficacy and watershed benefit of integrating hydraulic mine remediation activities into forestry projects. Due to the mercury-laden sediment at mine sites, development of management practices that minimize transport of mercury off site during and after fuels reduction are critical. The methodology behind utilization of a pilot model hinges on the scale of restoration and remediation required. Given the sheer acreage of TNF land in need of fuels treatment coupled with the number of hydraulic mine sites, this effort has a manageable scope with the potential to increase durability of investment by HMSR-TAC partners through replication.

Strategy for Mercury in Forest and Land Management

Identify and prioritize the location of fuels reduction projects that use best available technologies and management practices to reduce wildfire risk in the vicinity of hydraulic mines.

The integration of mine remediation and forest management represents an opportunity to improve forest heath and reduce wildfire risk. This will lead to multiple benefits including the protection of watersheds and water storage facilities from sediment and mercury loading. The development of a monitoring plan and collection of baseline pre-implementation data will facilitate the evaluation of forest management activities, contributing to a regional understanding of best management practices (BMPs) that increase watershed resiliency.

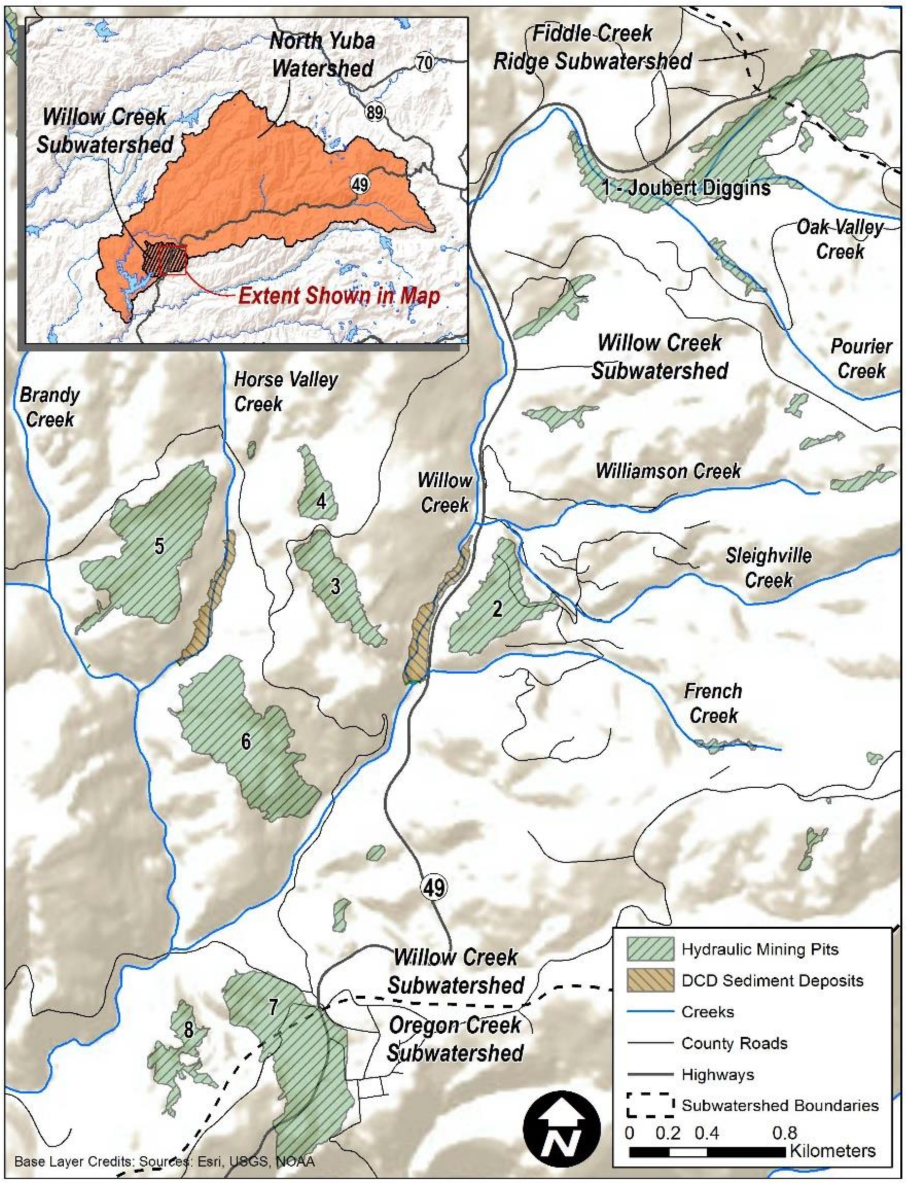

Figure 16: ***Resilient Forests in Mining-Impacted Landscapes***
The geographic scope of a Headwater Mercury Source Reduction hydraulic mines and mine features pilot project on Tahoe National Forest.

Actions

Action 1: Develop a database of mine-impacted forests*. Develop a database of forested areas with high fuel loading and hydraulic mines.*

This database will identify hydraulic mines prone to erosion, sediment transport, and mercury release that are located in areas identified as severe fire risk areas. The TNF LiDAR data, Cal Fire Very High Fire Hazard Severity Zone (VHFHSZ) maps, satellite imagery, state databases and the Inventory and Database developed as part of the HMSR Strategy for Hydraulic Mines and Mine Features will be used to inventory hydraulic mines in forested areas. Mines in forested areas on TNF land will be included in the database.

Action 2: Ground truth areas identified in the mine-impacted forests database*. Check the accuracy of remotely sensed data and maps with site visits and collect baseline data for site prioritization.*

The locations and conditions of site features will be recorded using mobile data collection devices (Apple iPhones) and the geographic data collection application Avenza. Baseline data on fuel loading will be collected based on parameters that include:

1. Volume of surface fuels (vegetation and downed woody material.
2. Volume of ladder fuels (vertical plant matter that helps fire spread into trees.
3. Forest density.

Surface fuels will be estimated using methods for calculating large woody debris (LWD) while ladder fuels and forest density will be estimated based on diameter at breast height (DBH) and number of trees per acre. TNF LiDAR derived "EcObject Vegetation Map" will also be used to estimate acreage of fuels based on risk category.

Action 3: Rank and prioritize mine-impacted forests for fuels reduction*. Forested areas with hydraulic mines should be prioritized for management activities based on potential for high severity fire and erosion.*

Mine-impacted forested areas can be ranked based on extent of fuel loading, potential for erosion, potential for mercury transport, level of mercury contamination, proximity to water bodies, and risk to human life and livelihood as measured by distance to residential homes, populated areas, or community centers.

Action 4: Develop pilot projects and evaluate treatments in mine-impacted forests*. Design and implement pilot projects that improve forest health around and in mine-scarred lands, including monitoring activities to evaluate the effectiveness of key treatments.*

Pilot projects will implement key forest restoration activities, including:

1. Fuels treatments to reduce fire severity.

2. Applying wood chips to denuded landscapes to reduce erosion.

3. Applying biochar to contaminated soils to reduce mercury transport.

An Effectiveness Monitoring Plan (EMP) will be developed to evaluate how successfully project activities reduce sediment and mercury transport. The EMP will include a Sampling and Analysis Protocol (SAP) to ensure quality control. Monitoring protocols will ensure that project activities contribute to regional understanding of how to reduce mercury transport as part of forest management. Sediment and water samples will be collected using Ultra Clean Hands techniques for trace metal sampling (USEPA, 1996).

Action 5: Make recommendations and evaluate best-practices for forest management in mine-impacted landscapes. *Best-practices developed as a result of pilot implementation of integrated fuels reduction and hydraulic mine remediation can be replicated across Sierra Nevada forests.*

The implementation of best-practices will increase the likelihood of landscape-scale improvements in forest and watershed resiliency.

Outcome of Strategy Implementation for Mercury and Forest Management

Decreased potential for transport of mercury into aquatic ecosystems due to high intensity wildfire that results in erosion of mercury-contaminated sediment and/or volatilization and subsequent atmospheric deposition of mercury.

Strategy Implementation Evaluation Criteria

- Development of a Sampling and Analysis Plan that can be used for evaluation of forest management activities that reduce headwater sources of mercury.
- Successful design and implementation of a pilot project that integrates fuels reduction with mine remediation activities.
- Development of best-practices for fire-safe revegetation of mine-contaminated soils.

Strategic Target 3: Mercury-Contaminated Sediment in Reservoirs

Background

Reservoirs downstream of mercury sources capture sediment and mercury, and fish in such reservoirs are contaminated with mercury. Furthermore, when reservoir dams overtop, mercury-contaminated sediment is transported downstream. See Page 42, Figure 17. Managers of reservoirs downstream of legacy sources contend that source control at mine sites is as important a strategy as controlling methylation and bioaccumulation processes in reservoirs (SWRCB, 2017).

Figure 17: ***Combie Reservoir Dam***
Foothill reservoirs capture and retain sediment, however, when dams overtop during the rainy season mercury and sediment is transported further downstream. Photo Source: Carrie Monohan.

Scope

The Statewide Mercury Control Program being developed by the State Water Resources Control Board (SWRCB) and nine Regional Water Quality Control Boards (RWQCB), including the Central Valley Regional Water Quality Control Board (CVRWQCB, Region 5), includes the development of a new reservoir-specific TMDL to limit mercury contamination in reservoirs, which could limit the release of mercury contaminated discharges. To inform this effort, data from more than 90 of these reservoirs were used in statistical analyses conducted by the SWRCB to assess the influence of almost 40 factors on methylmercury concentrations in predatory fish (SWRCB, 2013, p.4). This analysis found that three factors together explain most of the variability in fish methylmercury concentrations in California reservoirs (SWRCB, 2013, p. 4). These variables include:

1. Aqueous total mercury (reflects the overall magnitude of mercury sources to the reservoir and thus methylmercury potential).

2. Ratio of aqueous methylmercury/[chlorophyll-a] (the relative magnitude of methylmercury entering the food chain).

3. The magnitude of water level fluctuation.

The TMDL implementation plan for mercury in reservoirs will require reservoir managers to conduct pilot tests on how to reduce MeHg in fish. This makes a strategy to address mercury-contaminated sediment in reservoirs both timely and useful. In terms of reservoir processes, understanding the conditions that promote mercury methylation in the reservoir and the fraction of sediment-associated mercury that can remobilize for transport to the water and subsequently downstream will provide insight into how to coordinate, design, and implement control studies and ultimately how to manage the contaminant (Kuwabara et al., 2003, p. 10). The extent to which existing practices in reservoir management (water releases, sediment removal, drawdowns etc.) affects mercury fate and transport should be monitored and best-practices for reservoir management in mercury impacted watersheds should be developed.

Strategy for the Removal of Mercury-Contaminated Sediment from Reservoirs

Develop and apply best available technologies and methods to prioritize and remove mercury-contaminated sediment from reservoirs.

Sediment management is a component of mercury source reduction in the headwaters due to the strong association between fine-grained sediment that is mobilized during storm events and mercury. Research by USGS, TSF and others has demonstrated that suspended sediment discharging from hydraulic mine sites has particulate-bound mercury and that this material is transported downstream and into reservoirs. Sediment removal activities at reservoirs thus also serve to remove mercury from the aquatic environment, reducing the amount of inorganic Hg available for methylation and reducing the mercury load passing downstream to the San Francisco Bay-Delta.

This Strategy will be informed by the findings of USGS researchers and in collaboration with reservoir managers as part of an effort to monitor and evaluate the implementation of mercury-contaminated sediment removal activities being undertaken by the Nevada Irrigation District (NID) at Combie Reservoir (funded by a $6.13 million allocation in California's 2017/2018 budget).

Actions

Action 1: Develop database of reservoirs impacted by mercury-contaminated sediment*.* *Creation of a database of reservoirs that includes their rate of sedimentation, water storage capacity, level of mercury contamination and vulnerability to climate change.*

Action 2: Baseline sampling*. Sample sediment, water, pore water, and biota for mercury to quantify contamination at reservoirs so that sites can be monitored for trends over time, including pre and post sediment removal activities.*

Sediment, water, biota, and fish samples will be collected using Ultra Clean Hands techniques for trace metal sampling (USEPA, 1996).

Action 3: Rank and prioritize reservoirs for remediation and for pilot projects*. Develop criteria for the selection and prioritization of reservoirs for comprehensive assessment and remediation.*

Reservoirs impacted by mercury-contaminated sediment can be ranked based on the following:

1. Level of contamination (sediment, water, pore water, biota, human exposure potential (fish tissue mercury levels).

2. Mercury methylation potential (dissolved oxygen demand, trophic status).

3. Sedimentation risk (geology, presence/absence of upstream hydraulic mines).

4. Economic value (number of water users served, presence/absence of hydroelectric infrastructure).

Criteria developed for ranking should be consistent with the criteria under development by the SWRCB to prioritize reservoirs for implementation of pilot projects as part of the new reservoir TMDL.

Action 4: Make recommendations and monitor implementation of best-practices for reservoir remediation*. Monitor and assess potential best-practices and make recommendations based on the results.*

Best-practices for assessing, prioritizing and remediating reservoirs will continue to be developed and modified based on the above actions and incorporated into this document annually to inform future efforts in the region.

Sediment removal from reservoirs must minimize the creation of turbid conditions during the warmer months of the year. This can be accomplished by removing sediment in dry conditions (out of the active channel) which minimizes the creation of turbid water during sediment removal operations.

Current best practices for reducing mercury transport and methylation in reservoirs include:

- **Reducing Contamination from Reservoirs - Best Practice 1:** Minimize the creation of turbid conditions. The disturbance of silts and clays should be limited during sediment removal operations especially in warm months when anoxic zones form more readily in the environment.

Dewatering deposits and flushing dewatering channels can promote aeration and minimize stratification and the subsequent establishment of anoxic zones with methylation-prone conditions. This can be accomplished by creating a flowing dewatering channel in the deposit. To reduce the activity of potential sulfate or iron reducing bacteria in low flow channels, the channel can be flushed with river water, which limits the methylation potential. This can be accomplished by connecting the active channel to a dewatering channel, thus providing a constant flow of water through the dewatering channel.

- **Reducing Contamination from Reservoirs - Best Practice 2:** Minimize the creation of low-oxygen conditions. Mercury methylation can occur in anoxic zones found in shallow water, groundwater and dewatering channels. These conditions can be avoided by removal in the dry and flushing dewatering channels.

Criteria for an activity to be designated a best-practice will be developed by the HMSR-TAC. Best-practices are expected to evolve over time as additional methods and strategies are identified through pilot-scale implementation.

Outcome of Strategy Implementation for Mercury-Contaminated Sediment in Reservoirs

Removal of mercury contaminated sediment from reservoirs could provide multiple benefits, including restored water storage space, sellable aggregate, recovered gold, and reduction of the conditions for mercury methylation, by removing inorganic mercury in the sediment deposit and creating cooler and deeper benthic environments.

Strategy Implementation Evaluation Criteria

- Support the development of at least one sediment removal project per year in partnership with reservoir managers.
- Develop monitoring plans for reservoir sediment removal projects led by irrigation districts and others.
- Identify and characterize mercury-reduction best practices for reservoir maintenance activities including sediment removal.
- Support reservoir sediment removal efforts in other mining-impacted regions by sharing monitoring strategies and best-practices.
- Coordinate best practices into regional regulatory and planning efforts such as the Reservoir Mercury TMDL.

Current needs for the implementation of this strategic approach include the evaluation of reservoirs in the Yuba and Bear River watersheds and the selection of reservoirs in this region for control studies that would inform the SWRCB's Reservoir Mercury TMDL and other activities. This includes reservoirs with dams that are currently blocking fish passage and that have been deemed impossible to modify or remove because of the contaminated sediment they hold.

Strategic Target 4: Mercury Exposure via Fish Consumption

Background

Consumption of contaminated fish is the main route of human exposure to mercury (Carrasco et al., 2011; Engelberth et al., 2013; Lepak et al., 2009; May et al., 2000; Wiener and Suchanek, 2008). Data indicate that some fish in mining impacted regions can have very high levels of mercury (>1 ppm) in their tissue, potentially posing a threat to public health (May et al., 2000).

Within the State of California, the Office of Environmental Health Hazard Assessment (OEHHA) is the public health agency responsible for the development of fish consumption advisories. When developing fish consumption advisories based on mercury, OEHHA compares mercury concentrations (often the arithmetic mean) in fish tissue for each species to the Advisory Tissue Levels (ATLs) for methylmercury (OEHHA, 2008). ATLs "provide a number of recommended fish servings that correspond to the range of contaminant concentrations found in fish and are designed to prevent consumers from being exposed to more than the average daily reference dose for non-carcinogens" (OEHHA, 2008).

Most advisories that OEHHA issues are for a specific site, such as a bay, river, or reservoir. OEHHA issues site-specific fish consumption advisories for water bodies with sufficient fish tissue data. Site-specific data are preferred in developing fish advisories because they more accurately represent the conditions of a water body, its fish species population, and their contaminant concentrations.

OEHHA has also issued several advisories that apply to water bodies that lack site-specific advices including California Lakes and Reservoirs Without Site-Specific Advice, California Coastal Locations Without Site-Specific Advice, and Fish that Migrate. These advisories are developed using large datasets and are very protective as they apply to water bodies that may have considerable variation in fish mercury levels across them. For example, the Statewide Advisory for Eating Fish from California's Lakes and Reservoirs Without Site-Specific Advice applies to all lakes and reservoirs that lack sufficient data or have yet to be evaluated. It was developed using samples from hundreds of water bodies across the state where advisories had not been issued at that time (Lim et al., 2013). Because of the uncertainty related to the mercury levels in fish caught from these water bodies, OEHHA used a more health-protective approach in developing the Statewide Advisory. They used the 90th percentile value of the mean mercury concentration in fish tissue rather than the average in developing the statewide advisory (Lim et al., 2013).

Scope

The Cosumnes, American, Bear, Yuba (CABY) watershed region has some of the most mining and thus mercury-impacted water bodies in the state. See Page 47, Figure 18. Many CABY region water bodies with known mercury contamination that are on the Clean Water Act Section 303(d) list for impairment, lack the necessary fish tissue data for OEHHA to establish site-specific fish consumption advice (OEHHA, 2009). However, many site-specific fish consumption advisories issued for black bass in CABY region watersheds (Combie Reservoir; Camp Far West Reservoir; Lake Englebright; New Bullards Bar Reservoir, Lower American River, Lower Cosumnes River, Yuba River - South, North, Middle, and Bear River) lists it as a "do not eat" species for sensitive populations (Group 1: Women ages 18-49 and children ages 1 to 17 years). Angler survey research in the Gold Country indicates that the lakes and reservoirs of the CABY region are popular local fishing locations frequented by anglers who eat their catch and feed it to members of their family (Monohan, 2011; Monohan and Keeble-Toll, 2018).

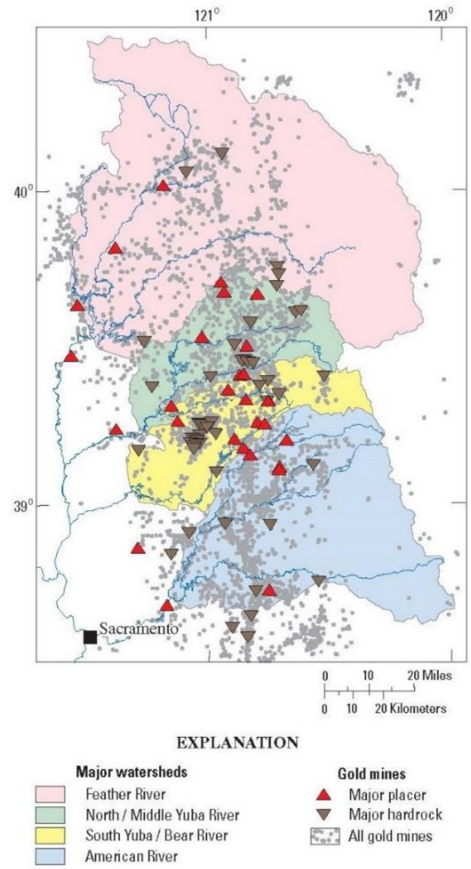

Figure 18: ***Mining-Impacted Watersheds in the CABY Region***
The Yuba, Bear, and American Rivers of the CABY watershed region were the location of significant historic gold mining activities. Figure Source: USGS Fact Sheet 2005_3014_v1.1.

Strategy for Reducing Mercury Exposure via Fish Consumption

Increase the amount and accessibility of information about mercury in locally caught fish.

The overarching goal of this Strategy is to provide the public with actionable information about the three critical components of healthy local fish consumption:

1. Species of fish being consumed.

2. Population group consuming the fish (women 18 to 49 years (typically considered childbearing age) and children 1 to 17 years; and women over 50 years and men).

3. Frequency of consumption.

In addition, a key goal is to provide more site-specific fish tissue data to inform the accuracy and usefulness of public health information on mercury in fish. Anglers should have access to and understand fish consumption advisories so that they can enjoy low-mercury local fish as a healthy addition to their diet.

Actions

Action 1: Collect regional angler survey data*. Angler Surveys provide key information about regional catch and consumption patterns that can be used both for informing sampling plans for fish tissue data collection and for informing best-practices for the dissemination of public health information.*

Species consumed varies regionally and even locally and depends on a suite of factors including cultural background, socio-economic status, educational attainment level, ethnicity, income, age, and gender (Lepak et al., 2009; Shilling et al., 2010). Consequently, it is crucial to understand the preferences of local anglers.

Action 2: Collect regional fish tissue data*. The ability of OEHHA to develop and issue site-specific fish consumption advisories that are protective of human health is contingent upon the availability of adequate fish tissue data.*

Procedures used for field sampling for fish tissue collection are adapted from the SWAMP Bioaccumulation Oversight Group (BOG) 2014 Clean Lakes Study plan (Sampling and Analysis Plan for a Study of Lakes and Reservoirs with Low Concentrations of Contaminants in Sport Fish). See Figure 19. All mercury analysis of fish tissue samples will be conducted by a certified trace metals laboratory, such as Brooks Applied Labs (EPA laboratory code WA00252) of Bothell, WA.

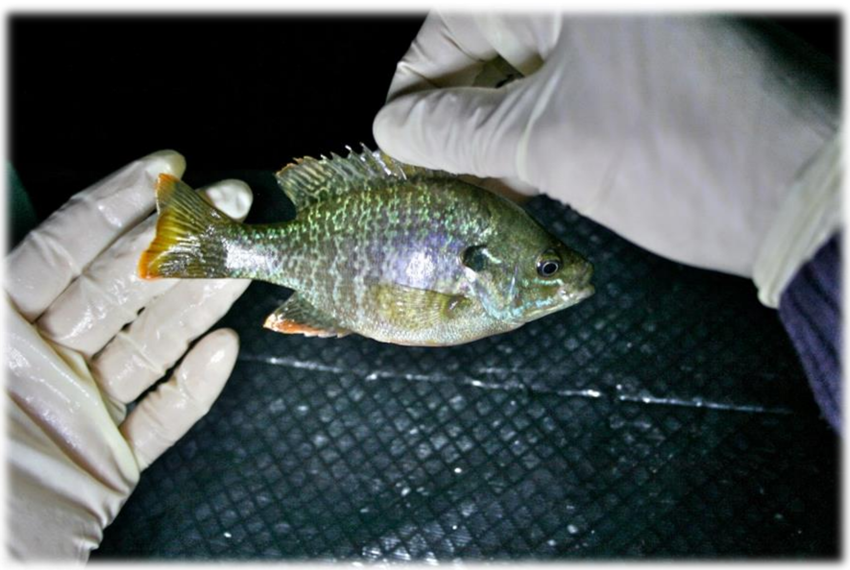

Figure 19: ***Fish Tissue Sampling***
Using the Ultra Clean Hands method in the field for the collection of a Sunfish at Lake Clementine for mercury analysis. Photo Source: Alex Keeble-Toll.

Action 3: Use angler survey and fish tissue data to identify water bodies with high risk of exposure*. Water bodies that pose a high risk of exposure should be identified and posted with state-issued fish consumption advisories and additional outreach to ensure that anglers understand and can use this information should be conducted through community groups, WIC programs and other venues that reach sensitive populations for mercury exposure.*

Water bodies where surveyed anglers report high rates of local fish consumption, low levels of knowledge about safe fish consumption and that have high fish tissue levels should be prioritized for public health outreach, including the posting of fish consumption advisories to increase access to important information about mercury.

Action 4: Post state-issued fish consumption advisories at water bodies statewide*. OEHHA develops and issues fish consumption advisories, however, there is no requirement that water body managers post on site at popular public fishing locations.*

OEHHA releases new site-specific advice as new data become available and their staff are able to evaluate the data and assess potential human health impacts. OEHHA fish consumption advisories are posted on their website, as are the scientific reports that form the basis for the advisories (http://oehha.ca.gov/fish/advisories). The actual posting of fish consumption advisories at water bodies where they apply represents a gap in data communication that must be filled to ensure that this important public health information is made accessible to those who consume locally caught fish. Inconsistency in posting of advisories can mislead anglers into believing that if there is no posted advice, the fish must be safe to eat. Water bodies that lack site-specific advice should post the applicable non-site-specific advisory, if possible.

Action 5: Utilize angler survey and fish tissue data to develop best practices for targeted outreach and regulatory actions*. Data about local fish consumption and fish tissue mercury levels should be evaluated to ensure that public health information is understandable and actionable, and specifically that it is made accessible to vulnerable communities.*

Though many water managers (such as Nevada Irrigation District and Santa Clara Valley Water District) as well as NGOs like TSF have worked to post fish consumption advisories, these efforts have been regionally specific. To ensure consistent posting of this public health information it may be necessary to pursue regulatory action that requires posting.

Making this information more accessible through the posting of state-issued fish consumption advisories is critical, however, a more in-depth approach may be required to ensure that populations that consume locally caught fish know how to utilize the information contained in fish advisories to protect their health. Data from TSF's *Gold Country Angler Survey: 2018 Update* will be analyzed in conjunction with fish tissue data to target sites for health outreach that are known to have angler activity and high (>0.3 ppm) fish mercury concentrations. (Shilling, 2003).

Findings of the *Gold Country Angler Survey: 2018 Update* showed that of those surveyed that had seen some type of health-related warning about mercury in fish only 1% had accurate understanding that would allow them to protect their health (Monohan and Keeble-Toll, 2018).

There is evidence to suggest that further analysis should be done to determine any demographic trends in anglers surveyed to see if race/ethnicity may play a role in the inability of anglers to articulate fish consumption advice. For example, Judd et al. (2015) has found fish advisories to be an ineffective tool for risk management in tribal communities. This is because consumption advisories fail to consider the complex social factors that influence fish consumption including issues of culture, food access, and nutrition (Judd et al., 2015). Findings from Beehler et al. (2003) suggest that successful risk reduction strategies must move beyond written risk communication and provide educational intervention that integrates local knowledge and lifestyles. Other evidence suggests that if even anglers report having heard or seen health warnings about eating fish and are able to articulate information from the posted advice it may not lead to changes in behavior that reduce exposure.

The medium of communication may not play a role in improving outcomes. In an analysis of angler surveys done in the Central Valley, Shilling et al. (2010) found no statistically different rates of fish consumption (and thus mercury exposure) among anglers that were more aware of warnings than anglers with low awareness.

Action 6: Work with the medical community to design an epidemiological study. *Public health research needs to be conducted in order to qualify and quantify the health impacts of mercury exposure in California.*

A better understanding of the scope and severity of human health impacts due to exposure to mercury via the consumption of contaminated fish is key to informing how to protect public health in the Sierra Nevada and downstream communities. Furthermore, this research can be used to educate doctors, nurses, and other health service providers about mercury exposure in a public health workshop setting to ensure that this information is being communicated to the men, women and children they serve.

Outcome of Strategy Implementation for Mercury Exposure via Fish Consumption

By increasing the amount and accessibility of information on mercury in local fish species residents and visitors of the Sierra Nevada will be empowered to protect their health while enjoying the full beneficial use value of mining-impacted water bodies.

Strategy Implementation Evaluation Criteria

- Fish tissue data gaps are identified as part of Action 2 filled and data are provided to OEHHA.
- Fish consumption advisories are posted in Spanish at CABY region waterbodies and posted in additional languages as identified through analysis of Angler Survey data.
- Outreach strategy is developed for vulnerable communities as identified based on angler activity and high fish tissue mercury levels.
- Follow-up outreach to local public health officials is conducted to ensure that they are aware of the need to provide information about mercury in fish to the Sierra Nevada populations they serve.
- Angler survey data collection effort expanded to the mercury-impacted Feather River watershed (n=30).
- Established fish advisory posting protocols that provide consistent posting to protect human health across the region.

DOCUMENT DRAFTS AND REVISIONS

The Headwater Mercury Source Reduction Strategy

The Strategy is a living document that is updated following the quarterly meetings of the Technical Advisory Committee (HMSR-TAC) to reflect the current state of understanding of the four strategic targets. Each subsequent draft of the document is denoted with an ascending version number and date, and members of the HMSR-TAC are invited to provide comments and feedback to the draft. The HMSR Strategy is the only written product of the TAC. The Strategy will be updated following the *Reclaiming the Sierra 2019: Headwater Mercury Source Reduction* conference with key policy actions to pursue in relation to each target for mercury.

Document Review Process

The HMSR-TAC will review documents relevant to their mission as requested. Documents should be submitted in electronic form at least two weeks prior to a quarterly HMSR-TAC meeting for discussion at the meeting. Documents, with the exception of the HMSR Strategy, will not be a product of the HMSR-TAC. Individual review of relevant information may also be sought from HMSR-TAC members via email.

TAC PARTICIPATION AND PROTOCOLS

Partnership

Technical experts from organizations and agencies will be invited to sign the voluntary HMSR Strategy Resolution of Support and will be listed at the beginning of the HMSR Strategy document as having signed the resolution and on the HMSR page on TSF's website in the future. The meetings of the HMSR-TAC are not public; however, we aim to recruit additional experts and key stakeholders to the forum as relevant to the four strategic foci. Please contact TSF with suggestions for additional interested persons.

Decision Making

HMSR-TAC members will work toward reaching consensus on the issues addressed. All decisions will be made at the quarterly meetings by those members present unless prior notification is made via email specifying otherwise.

Meetings

HMSR-TAC meetings are held quarterly. Proposed dates for future meetings will be identified during scheduled meetings and formal save-the-date and draft agendas will be sent to forum participants a minimum of 6 weeks in advance of the next scheduled meeting. Past meeting notes and agendas are available by request.

Facilitation

HMSR-TAC meetings will be facilitated by staff of TSF, at the will of the HMSR-TAC members. Facilitator(s) will guide participants in discussion in a manner that is focused and respectful and within the timeframe specified by the applicable forum agenda.

Ground Rules

HMSR-TAC members agree to follow and enforce ground-rules to ensure that a collaborative and respectful environment is fostered and maintained at forum meetings:

- Keep discussion focused.
- Give all participants a chance to speak.
- Be brief and to-the-point.
- Do not interrupt fellow stakeholders.

Photo by: Alex Keeble-Toll

References

Adams, L. and Denton, J.E. 2008. Development of Fish Contaminant Goals and Advisory Tissue Levels for Common Contaminants in California Sport Fish: Chlordane, DDTs, Dieldrin, Methylmercury, PCBs, Selenium, and Toxaphene. California Environmental Protection Agency & Office of Environmental Health Hazard Assessment.

Ackerman, J.T., Hartman, C. A., Eagles-Smith, C.A., Herzog, M.P., Davis, J., Ichikawa, G., and Bonnema, A. 2015. Estimating Exposure of Piscivorous Birds and Sport Fish to Mercury in California Lakes Using Prey Fish Monitoring – A Predictive Tool for Managers: U.S. Geological Survey Open-File Report 2015-1106, 48 p., http://dx.doi.org/10.3133/ofr20151106.

Alpers, C.N., Hunerlach, M.P., Hothem, R.L., and May, J.T. 2005a. Mercury Contamination from Historic Gold Mining in California: U.S. Geological Survey Fact Sheet 2005: 3014, 6p., http://water.usgs.gov/pubs/fs/2005/3014/.

Alpers, C.N., Hunerlach, M.P., May, J.T., Hothem, R.L., Taylor, H.E., Antweiler, R.C., De Wild, J.F., and Lawler, D.A. 2005b. Geochemical Characterization of Water, Sediment, and Biota Affected by Mercury Contamination and Acidic Drainage from Historic Gold Mining, Greenhorn Creek, Nevada County, California, 1999-2001. United States Geological Survey Scientific Investigations Report 2004-5251.

Alpers, C.N., May, J.T., Hothem, R.L., May, T.W., and Saiki, M.K. 2008. Mercury Bioaccumulation in the Bear River Watershed, Northern Sierra Nevada, California, 2003-06. U.S. Geological Survey Open-File Report.

Alpers, C.N., Stewart, A.R., Saiki, M.K., Marvin-DiPasquale, M.C., Topping, B.R., Rider, K.M., Gallanthine, S.K., Kester, C.A., Rye, R.O., Antweiler, R.C., and De Wild, J.F., 2008, Environmental factors affecting mercury in Camp Far West Reservoir, California, 2001–03: U.S. Geological Survey Scientific Investigations Report 2006-5008, 358 p.

Alpers, C.N., Yee, J.L., Ackerman, J.A., Orlando, J.L., Slotton, D.G., and Marvin-DiPasquale, M. 2016. Prediction of fish and sediment mercury in streams using landscape variables and historical mining. Science of the Total Environment. 571. 10.1016/j.scitotenv.2016.05.088.

ATSDR, 1999, Public Health Statement, Mercury, CAS#: 7439-97-6: Agency for Toxic Substances and Disease Registry, March 1999: http://www.atsdr.cdc.gov/ (accessed June 2016).

Arkle, R.S., Pilliod, D.S., 2009. Prescribed fires as ecological surrogates for wildfires: A stream and riparian perspective. Forest Ecology and Management v. 259, p. 893-903.

Beche, L.A., Stephens, S.L., Resh, V.H., 2005. Effects of prescribed fire on a Sierra Nevada (California, USA) stream and its riparian zone. Forest Ecology and Management v. 218, p. 37-59.

Beehler, G.P. McGuinness, B.M., and Vena, J.E. 2003. Characterizing Latino Anglers' Environmental Risk Perceptions, Sport Fish Consumption, and Advisory Awareness. Medical Anthropology Quarterly, New Series, v. 17:1, p. 99-116.

Beesley, L., Moreno-Jimenez, E., Gomez-Eyles, J., Harris, E., Robinson, B., and Sizmur, T. 2011. A review of biochar's potential role in the remediation, revegetation and restoration of contaminated soils. Environmental Pollution, v. 159, p. 3269-3282.

Boer, M.M., Sadler, R.J., Wittkuhn, R.S., McCaw, L., Grierson, P.F., 2009. Long-term impacts of prescribed burning on regional extent and incidence of wildfires- Evidence from 50 years of active fire management in SW Australian forests. Forest Ecology and Management v. 259, p. 132-142.

Boudou, A., and Ribeyre, F., 1997, Mercury in the food web: Accumulation and transfer mechanism, in Sigel, A., and Siegl, H., eds., Metal ions in biological system: New York, New York, Dekker, p. 289-319.

Bowie, A.J., 1905, A practical treatise on hydraulic mining in California (10th ed.): New York, Van Nostrand, 313 *p

Brooks Rand Labs, 2013, Sample Homogenization, Seattle, Washington, SOP BR-0106.

Bureau of Land Management. FY2006-FY2013. Abandoned Mine Land Workplan. California State Office.

Bureau of Land Management. 2005. Boston Placer Mine Sluice Tunnel Remediation Project, Red Dog, California. State Program for Hazardous Materials/Abandoned Mine Lands/Natural Resource Damage Assessment and Restoration: John_Key@ca.blm.gov.

Bustic, V. McCann, H., Axelson, J., Gray, B., Jin, Y., Mount, J., Stephens, S., and Stewart, W. 2017. Improving the Health of California's Headwater Forests. Public Policy Institute of California: https://www.ppic.org/publication/improving-the-health-of-californias-headwater-forests/.

California Department of Conservation (CDOC). 1999. Abandoned Mine Lands Preliminary Assessment Handbook. Second Printing. https://www.dtsc.ca.gov/SiteCleanup/Brownfields/upload/aml_handbook.pdf

California Department of Conservation (CDOC). 2000a. California's Abandoned Mines, Volume I. Sacramento, CA: Office of Reclamation, Abandoned Mine Lands Unit.

California Department of Conservation (CDOC). 2000. California's Abandoned Mines, Volume 2. Sacramento, CA: Office of Reclamation, Abandoned Mine Lands Unit. California Department of Conservation. 2007. The Honorable Diane Feinstein, "Feinstein List." Office of Mine Reclamation.

California Environmental Protection Agency (Cal/EPA). December 2003. Evaluation of Potential Health Effects of Eating Fish from Selected Water ways in the Northern Sierra and Guidelines for Fish Consumption.

Campbell, P.G.C., Lewis, A.G., Chapman, P.M., Crowder, A.A., Fletcher, W.K., Imber, B., Louma, S.N., Stokes, P.M., and Winfrey, M., 1988, Biologically available metals in sediments (NRCC No. 27694): Ottawa, Ontario, National Research Council of Canada, 298 p.

Carrasco, L., Barata, C., Garcia-Berthou, E., Tobias, A. Bayona, J.M., and Diez S. 2011. Patterns of Mercury and Methylmercury Bioaccumulation in Fish Species Downstream of a Long-Term Mercury-Contaminated Site in the Lower Ebro River (NE Spain). Chemosphere v. 84, p. 1642-1649.

California Department of Forestry (CDF) Data. 2015. Cal Fire/Butte Fire General Information. http://cdfdata.fire.ca.gov/incidents/incidents_details_info?incident_id=1221

Churchill, R. 1999. Insights into California Mercury Production and Mercury Availability for the Gold Mining Industry from the Historical Record. Geological Society of America, Abstracts with Program, v. 31:6, p. 45.

Compeau, G.; Bartha, R. 1987. Effect of Salinity on Mercury-Methylating Activities of Sulfate-Reducing Bacteria in Estuarine Sediments. Applied and Environmental Microbiology, v. 53(2), p. 261-265

Central Valley Regional Water Quality Control Board (CVRWQCB). 1998. Water Quality Control Plan (Basin Plan) for the Sacramento River and San Joaquin River Basins, Fourth Edition. California Environmental Protection Agency.

Davis, J.A., Greenfield, B.K., Ichikawa, G. and Stephenson, M. 2008. Mercury in Sport Fish from the Sacramento-San Joaquin Delta Region, California. Science of the Total Environment v. 391, p. 66-75.

Delamore, K. 2013. Analysis of Soil Samples Using a Portable X-Ray Fluorescence Spectrometry (XRF). Marlborogh District Council. New Zealand.

Domagalski, J. 2001. Mercury and methylmercury in water and sediment of the Sacramento River Basin, California. Applied Geochemistry v. 16, p. 1677-1691.

Donovan, G.H., Brown, T.C., 2007. Be careful what you wish for: the legacy of Smokey Bear. Front, Ecol. Environ. v. 5, p. 73-79.

Eccles, C.U., and Annau, Z., 1987, The toxicity of methyl mercury: Baltimore, Maryland, The Johns Hopkins University Press, 259 p.

Elliot, W.J., Miller, M.E., and Enstice, N. 2016. Targeting Forest Management Through Fire and Erosion Modeling. International Journal of Wildland Fire v. 25, p. 876-887.

Engelberth, H., Teisl M.F., Frohmberg, E., Butts, K., Bell, K.P., Stableford, S., and Smith, A.E. 2013. Can Fish Consumption Advisories Do Better? Providing Benefit and Risk Information to Increase Knowledge. Environmental Research v. 126, p. 232-239.

Fellet, G. Marchiol, L., Vedove, G. D., and Peressotti, A. 2011. Application of biochar on mine tailings: Effects and perspectives for land reclamation. Chemosphere, v. 83, p. 1262-1267.

Fernandez-Martinez, R., Loredo, J., Ordonez, A., and Rucandio, M.I. 2005. Distribution and Mobility of Mercury in Soils from an old Mining Area in Mieres, Asturias (Spain). Science of the Total Environment v. 346, p. 200-212.

Fish and Game Commission, 2014, California Sport Fishing Regulations Freshwater Edition 2014-2015, 75 p.

Fleck, J.A.., Alpers, C.N., Marvin-DiPasquale, M., Hothem, R.L., Wright, S.A., Ellett, K., Beaulieu, E., Agee, J.L., Kakouros, E., Kieu, L.H., Eberl, D.D., Blum, A.E., and May, J.T., 2011, The effects of sediment and mercury mobilization in the South Yuba River and Humbug Creek Confluence Area, Nevada County, California: Concentrations, speciation, and environmental fate—Part 1: Field characterization: U.S. Geological Survey Open-File Report, 2010-1325A, 104 p.

Fleming, E. J., E. E. Mack, P. G. Green, and D. C. Nelson. 2006. Mercury methylation from unexpected sources: molybdate-inhibited freshwater sediments and an iron-reducing bacterium. Appl. Environ. Microbiol. v. 72, p. 457–464.

Foe, C. S. Louie, and D. Bosworth. 2008. Methylmercury Concentrations and Loads in the Central Valley and Freshwater Delta. CALFED Task 2 of this project.

Gassel, M., and Brodberg, R.K. 2005. General Protocol for Sport Fish Sampling and Analysis. Pesticide and Environmental Toxicology Branch, Office of Environmental Health Hazard Assessment, California Environmental Protection Agency.

Gilmour, C. C.; Henry, E. A.; Mitchell, R. 1992. Sulfate Stimulation of Mercury Methylation in Freshwater Sediments. Environ. Sci. Technol. v. 26, p. 2281.

Gleason A., Hovda D.A., Katayama Y., Kawamata T., and Becker D.P., 1963, Lesion prevents Post-concussive metabolic dysfunction in CA1: Journal of Cerebral Blood Flow Metabolism, v. 12, p. 996–1006.

Gochfeld, M. 2003. Cases of Mercury Exposure, Bioavailability, and Absorption. Ecotoxicology and Environmental Safety v. 56(1), p. 174-179.

Herger, L. and Edmond, L. 2012. Assessment of Mercury in Fish Tissue from Select Lakes of Northeastern Oregon: EPA Region 10 Report. The United States Environmental Protection Agency, Region 10.

Humphreys, R., 2005, Mercury losses and recovery during a suction dredge test in the south fork of the American River: Sacramento, California, California State Water Board Staff Report, 12 p.

Hunerlach, M.P., Rytuba, J.J., and Alpers, C.N. 1999. Mercury Contamination from Hydraulic Placer-Gold Mining in the Dutch Flat Mining District, California. U.S. Geological Survey Water-Resources Investigations Report, 99-4018B, p. 179-189.

Hunerlach, M.P., Alpers, C.N., Marvin-DiPasquale, M., Taylor, H.E., and De Wild, J.F., 2004, Geochemistry of mercury and other trace elements in fluvial tailings upstream of Daguerre Point Dam, Yuba River, California, August 2001: U.S. Geological Survey Scientific Investigations Report 2004-5165, 66 p.

Kerin et al., 2006. Mercury Methylation by Dissimilatory Iron-Reducing Bacteria. Appl. Environ. Microbiol. v. 72, p. 7919–7921

Jackson, W.T., 1967, The North Bloomfield Mining District: Report on the Malakoff Mine, The North Bloomfield Mining District, and the Town of North Bloomfield.

Jakus, P.M., Dadakas, D., and Fly, J.M. 1998. Fish Consumption Advisories: Incorporating Angler-Specific Knowledge, Habits, and Catch Rates in a Site Choice Model. American Journal of Agricultural Economics, v. 80:5, p. 1019-1024.

James, A. 2005. Sediment from hydraulic mining detained by Englebright and small dams in the Yuba Basin. Geomorphology v. 71, p. 202-226.

Johnson, D.W., Murphy, J.F., Susfalk, R.B., Caldwell, T.G., Miller, W.W., Walker, R.F., and Powers, R.F. 2005. The effects of wildfire, salvage logging, and post-fire N-fixation on the nutrient budgets of a Sierran forest. Forest Ecology and Management, v. 220, p. 155-165.

Judd, N. Lownery, Y., Anderson, P., Baird, S., Bay, S.M., Breidt, J., Buonanduci, M., Dong, Z., Essig, D., Garry, M.R., Jim, R.C., Kirkwood, G., Moore, S., Niemi, C., O'Rourke, R., Ruffle, B., Schaider, L.A., and Vidal-Dorsch, D.E. 2015. Fish Consumption as a Driver of Risk-Management Decisions and Human Health-Based Water Quality Criteria. Environmental Toxicology and Chemistry, v. 34:11, p. 2427-2436.

Klasing, S. and Brodberg, R., 2003, Evaluation of Potential Health Effects of Eating Fish from Selected Water Bodies in the Northern Sierra Nevada Foothills (Nevada, Placer, and Yuba Counties): Guidelines for Sport Fish Consumption. Office of Environmental Health Hazard Assessment.

Kurland, L.T., Faro, S.N., and Siedler, H., 1960, Minamata disease: World Neurological Society, v. 1, p. 270-292.

Kuwabara, J.S., Alpers, C.N., Marvin-DiPasquale, M., Topping, B.R., Carter, J.L., Stewart, R.A., Fend, S.V., Parchaso, F., Moon, G.E., and Krabbenhoft, D.P. 2003. Sediment-Water Interactions Affecting Dissolved-Mercury Distributions in Camp Far West Reservoir, California. U.S. Geological Survey Water-Resources Investigations Report 03-4140.

Lepak, J.M., Shayler, H.A., Kraft, C.E., and Knuth, B.A. 2009. Mercury Contamination in Sport Fish in the Northeastern United States: Considerations for Future Data Collection. Bioscience v. 59:2, p. 174-181.

Lim, L., Brodberg, R.K., Gassel, M., and Klasing, S. 2013. Statewide Health Advisory and Guidelines for Eating Fish from California's Lakes and Reservoirs Without Site-Specific Advice, California Environmental Protection Agency & Office of Environmental Health Hazard Assessment.

Long, J.W., Quinn-Davidson, L. and Skinner, C.N. 2014. Science Synthesis to Support Sociological Resilience in the Sierra Nevada and Southern Cascade Range. Gen. Tech. Rep. PSW-GTR-247. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 723 p.

Lusk, J.D., Rich, E., and Bristol R.S. 2004. Methylmercury and Other Environmental Contaminants in Water and Fish Collected from Four Recreational Fishing Lakes on the Navajo Nation, 2004. Navajo Nation Environmental Protection Agency and United States Fish and Wildlife Service.

MacDonald, L.H. and Huffman, E.L. 2004. Post-Fire Soil Water Repellency: Persistence and Soil Moisture Thresholds. Soil Sci. Soc. Am. J., v. 68, p. 1729-1734.

Marine Pollution Studies Laboratory, 2007, Sampling Marine and Freshwater Bivalves, Fish and Crabs for Trace Metal and Synthetic Organic Analysis, Moss Landing, California, Method # MPSL-102a.

May, J.T., Hothem, R.L., Alpers, C.N., and Law, M.A. 2000. Mercury Bioaccumulation in Fish in a Region Affected by Historic Gold Mining: The South Yuba River, Deer Creek, and Bear River Watersheds, California, 1999. United States Geological Survey Open-File Report 00-367, 30 p. http://ca.water.usgs.gov/archive/reports/ofr00367/index.html.

Marvin-DiPasquale, M., and Agee, J.L., 2003, Microbial mercury cycling in sediments of the San Francisco Bay-Delta: Estuaries, v. 26, no. 6, p. 1517-1528.

Marvin-DiPasquale, M., Agee, J.L., Kakouros, E., Kieu, L.H., Fleck, J.A., and Alpers, C.N., 2011, The effects of sediment and mercury mobilization in the South Yuba River and Humbug Creek confluence area, Nevada County, California: Concentrations, speciation and environmental fate—Part 2: Laboratory Experiments: U.S. Geological Survey Open-File Report 2010−1325B, 54 p

McGinnis, S.M. eds. Farber, F.M. and Pavlik, B.M. 2006. California Natural History Guides: Field Guide to Freshwater Fishes of California. University of California Press, Berkeley and Los Angeles, California.

Minear, J.T. and G.M. Kondolf. 2009. Estimating reservoir sedimentation rates at large spatial and temporal scales: A case study of California. Water Resources Research, 45: W12502

Monohan, C. 2011. Gold Country Angler Survey: A Pilot Study to Assess Mercury Exposure from Sport Fish Consumption in the Sierra Nevada. https://www.sierrafund.org/angler-survey/.

Monohan, C. 2015. Humbug Creek Watershed Assessment and Management Recommendations: A Pilot Assessment of Mining Impacts and Recommendations for Action to Improve Water Quality at Malakoff Diggins State Historic Park. https://www.sierrafund.org/humbug-creek-report-2015/.

Monohan, C. and Keeble-Toll A.K. 2018. Gold Country Angler Survey: 2018 Update. **Available on the web in October 2019.*

Moody, J.A. and Martin D.A. 2001. Initial Hydrologic and Geomorphic Response Following a Wildfire in the Colorado Front Range. Earth Surface Processes and Landforms v. 26(10), p. 1049-1070.

Office of Environmental Health Hazard Assessment (OEHHA). 2001. Chemicals in Fish: Consumption of Fish and Shellfish in California and the United States. Final Report. Pesticide and Environmental Toxicology Section. Office of Environmental Health Hazard Assessment. California Environmental Protection Agency. Oakland, California.

Office of Environmental Health Hazard Assessment (OEHHA). 2008. Development of Fish Contaminant Goals for Advisory Tissue Levels for Common Contaminants in California Sport Fish: Chlordane, DDTs, Dieldrin, Methylmercury, PCBs, Selenium, and Toxaphene. Office of Environmental Health Hazard Assessment, California Environmental Protection Agency.

Office of Environmental Health Hazard Assessment (OEHHA). 2009. Update of California Sport Fish Advisories. Pesticide and Environmental Toxicology Branch, Office of Environmental Health Hazard Assessment, California Environmental Protection Agency.

Orlando, J. 2016, Hydraulic Mine Pits of California: U.S. Geological Survey data release, http://dx.doi.org/10.5066/F7J38QMD. also available at: https://www.sciencebase.gov/catalog/item/571976c2e4b071321fe22947.

Pacyna, J. M., Pacyna, E. G., Steenhuisen, F., and Wilson, S. 2003. Mapping 1995 global anthropogenic emissions of mercury, dynamic processes of mercury and other trace contaminants in the marine boundary layer of European seas – ELOISE II, Atmos. Environ., v. 37, p. 109–117.

Rytuba, J.J., Ashley, R., Slowey, A., J. Brown, G.E. & Foster, A. (2005). Mercury speciation and transport from historic placer gold and mercury mines, California. (Abstract). Geological Society of America, Abstracts with Programs, v. 37, p. 104.

Saiki, M.K., Martin, B.A., May, T.W., and Alpers, C.N. 2009. Mercury Concentrations in Fish From a Sierra Nevada Foothill Reservoir Located Downstream from Historic Gold-Mining Operations. Environ Monit Assess: DOI 10.1007/s10661-009-0836-6. Springer Science + Business Media B.V. 2009.

Scherer, A.C., Tsuchiya, A., Younglove, L.R., Burbacher, T.M., and Faustman, E.M. 2008. Comparative Analysis of State Fish Consumption Advisories Targeting Sensitive Populations. Environmental Health Perspectives v. 116:12, p. 1598-1606.

Shilling F. 2003. Background Information for a Central Valley Fish Consumption Study: Geographic Information System and Relational Database for Fish Tissue Mercury and Creel Survey Data. California Department of Fish and Game.

Shilling, F., Negrette, A., Biondini, L., and Cardenas, S. 2014. California Tribes Fish-Use: Final Report. State Water Resources Control Board and United States Environmental Protection Agency.

Shilling, F., White, A., Lippert, L., and Lubell, M. 2010. Contaminated Fish Consumption in California's Central Valley Delta. Environmental Research v. 110, p. 334-344.

Sierra Nevada Conservancy (SNC). 2014. The State of the Sierra Nevada's Forests Report. Sierra Nevada Conservancy, State of California. http://www.sierranevada.ca.gov/our-work/state-of-the-sierra.

Singer, M.B., Aalto, R., James, L.A., Kilham, N.E., Higson, J.L., Ghoshal, S., 2013, Enduring legacy of a toxic fan via episodic redistribution of California gold mining debris: Proceedings of the National Academy of Science of the United States of America, v. 110, i. 46, p. 18436–18441, doi: 10.1073/pnas.1302295110.

Slotton, D. G., Ayers, S. M., Reuter, J. E., & Goldman, C. R. 1997. Gold mining impacts on food chain mercury in northwestern Sierra Nevada streams. Technical Report, Division of Environmental Studies, University of California-Davis, Davis, CA, USA, 71 p.

Southwest Fire Science Consortium. 2013. Fuel Treatment Longevity. Ecological Restoration Institute, Working Paper No. 27.

State Water Resources Control Board (SWRCB). 2007. Bioaccumulation of Pollutants in California Waters: A Review of Historic Data and Assessment of Impacts on Fishing and Aquatic Life. Surface Water Ambient Monitoring Program (SWAMP). (Accessed 10/15/2014). www.waterboards.ca.gov/swamp.

State Water Resources Control Board (SWRCB). California Water Boards (CWB). 2013. Statewide Mercury Control Program for Reservoirs. California Water Boards Fact Sheet, September 2013. Sacramento, CA.

State Water Resources Control Board (SWRCB). California Water Boards (CWB). 2017. Draft Staff Report for Scientific Peer Review for the Amendment to the Water Quality Control Plan for Inland Surface Waters, Enclosed Bays, and Estuaries of California, Mercury Reservoir Provisions – Mercury TMDL and Implementation Program for Reservoirs. California Environmental Protection Agency. Sacramento, CA.

State Water Resources Control Board (SWRCB). California Water Boards (CWB). 2010. Final California 2010 Integrated Report (303(d) List/305(b) Report). www.waterboards.ca.gov/water_issues/programs/tmdl/2010state_ir_reports/01157.shtm#11187.

Steinwall, O., Olsson, Y. 1969. Impairment of the blood-brain barrier in mercury poisoning. Acta neurol. scand. v. 45**,** p. 351–361.

Stephens, S.L., Meixner, T., Poth, M., McGurk, B., and Payne, D. 2004. Prescribed fire, soils, and stream water chemistry in a watershed in the Lake Tahoe Basin, California. International Journal of Wildland Fire, v. 12, p. 27-35.

Stern, A.H. and Korn, L.R. 2011. An Approach for Quantitatively Balancing Methylmercury Risk and Omega-3 Benefit in Fish Consumption Advisories. Environmental Health Perspectives v. 119:8, p. 1043-1046.

Stewart, A.R., Saiki, M.K., Kuwabara, J.S., Alpers, C.N., Marvin-DiPasquale, M., and Krabbenhoft, M.P., 2008, Influence of plankton mercury dynamics and trophic pathways on mercury concentrations of top predator fish of a mining-impacted reservoir: Canadian Journal of Fisheries and Aquatic Sciences, v. 65, p. 2351–2366, doi:10.1139/ F08-140.

Stubblefield, A.P., Varner, M.J., Knapp, E.E., Harrison, N., and Banwell, E. 2007. Developing Fuels Treatments for Balancing Fuel Reduction, Soil Exposure, and Potential for Erosion in the Tahoe Basin (P019). Final Report SNLPMA Research Grant, USDA Forest Service: Pacific Southwest Research Station.

Tetra Tech EC, Inc. 2007. North Fork/Middle Fork American River Sediment Study: Prepared for American River Watershed Group. Lakewood, CO.

The Bioaccumulation Oversight Group (BOG). 2014. Sampling and Analysis Plan for a Study of Lakes and Reservoirs with Low Concentrations of Contaminants in Sport Fish: The Clean Lakes Study. Surface Water Ambient Monitoring Program (SWAMP).

United Nations Environment Programme (UNEP). 2002. Global Mercury Assessment, Tech. rep., UNEP, Geneva, Switzerland, www.chem.unep.ch/MERCURY/, 2002.

United States Department of Agriculture (USDA). 2015. The Rising Cost of Wildfire Operations: Effects on the Forest Service's Non-Fire Work. United States Department of Agriculture/United States Forest Service. http://www.fs.fed.us/sites/default/files/2015-Rising-Cost-Wildfire-Operations.pdf.

United States Department of Agriculture (USDA). 2011. Ecological Restoration Implementation Plan. United States Forest Service, Pacific Southwest Region. http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5411447.pdf.

United States Environmental Protection Agency (USEPA).2018. 2018 Edition of the Drinking Water Standards and Health Advisories Tables. U.S. EPA, Office of Water. EPA 822-F-18-001.

United States Environmental Protection Agency (USEPA), 2000, Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories: Volume 1, Fish Sampling and Analysis, Third Edition. EPA 823-R-93-002B-00-007.

United States Environmental Protection Agency (USEPA). 2002. Method 1631, Revision E: Mercury in Water by Oxidation, Purge, and Trap, and Cold Vapor Atomic Fluorescence Spectrometry. U.S. EPA, Office of Water, 4303. EPA-821-R-02-019.

United States Environmental Protection Agency (USEPA). 1996. Method 1669: Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels. U.S. EPA, Office of Water, Engineering and Analysis Division.

Van de Water, K. and North, M. 2011. Stand structure, fuel loads, and fire behavior in riparian and upland forests, Sierra Nevada Mountains, USA; a comparison of current and reconstructed conditions. Forest Ecology and Management, v. 262, p. 384-395.

Van de Water, K. and North, M. 2010. Fire history of coniferous riparian forests in the Sierra Nevada. Forest Ecology and Management, v. 260, p. 215-228.

Watras C.J., Back R.C., Halvorsen S., Hudson R.J.M., Morrison K.A. and S.P. Wente, 1998.Bioaccumulation of mercury in pelagic freshwater food webs. Science of the Total Environment v. 219, p. 183–208.

Williams, M.R and Melack J.M. 1997. Effects of Prescribed Burning and Drought on the Solute Chemistry of Mixed-Conifer Forest Streams of the Sierra Nevada, California. Biogeochemistry, v. 39, No. 3, p. 225-253

Wentz, D.A., Brigham, M.E., Chasar, L.C., Lutz, M.A., and Krabbenhoft, D.P. 2014. The Quality of Our Nation's Waters: Mercury in the Nation's Streams – Levels, Trends, and Implications. United States Department of the Interior, United States Geological Survey.

Wiener, J.G., Bodaly, R.A., Brown, S.S., Lucotte, M., Newman, M.C., Porcella, D.B., Reash, R.J., and Swain, E.B., 2007, Monitoring and evaluating trends in methylmercury accumulation in aquatic biota, in Ecosystem Responses to Mercury Contamination: Indicators of Change: Boca Raton, Florida, CRC Press/Taylor and Francis, p. 87-122.

Wiener, J.G., Gilmore C., and D.P. Krabbenhoft. 2003. Mercury Strategy for the Bay-Delta Ecosystem: A Unifying Framework for Science, Adaptive Management, and Ecological Restoration. Final Report to the California Bay Delta Authority. Dec 2003 http://www.calwater.ca.gov/content/Documents/library/tribal/MercuryStrategy_FinalReport_1-12-04.pdf.

Wiener, J.G., Krabbenhoft, D.P., Heinz, G.H., Scheuhammer, A., Hoffman, D., Burton, G.A.J., Cairns, J.J., 2003. Ecotoxicology of mercury. Handbook of Ecotoxicology.

Wiener, J.G., and Suchanek, T.H. 2008. The Basis for Ecotoxicological Concern in Aquatic Ecosystems Contaminated by Historical Mercury Mining. Ecological Applications v. 18:8, p. A3-A11.

Winch, S., Praharaj, T., Fortin, D., and Lean, D.R.S., 2008, Factors affecting methylmercury distributions in surficial acidic, base-metal mine tailings: Science of the Total Environment, v. 392, no. 2-3 p. 242-251.

Xu, H., and Allard, B., 1991, Effects of a fulvic acid on the speciation and mobility of mercury in aqueous solutions: Water, Air and Soil Pollution, v. 56, no. 1, p. 709-717.

Yoshino, S.R., Steinwall, W., Nicholson, R., Frigerg, M. and Chang, Y., 1966, The effect of mercury on the nervous system: Baltimore, Maryland, The Johns Hopkins University Press, 92 p.

Zhong, H., and Wang W, 2006, Effects of sediment composition on inorganic mercury partitioning, speciation and bioavailability in oxic-surficial sediments: Environmental Pollution, v. 151, p. 222-230.

Acronyms

ARD: Acid Rock Drainage

ATLs: Advisory Tissue Levels

BrB: Brown Bullhead

BlkB: Black Bullhead

BG: Bluegill

BOG: Bioaccumulation Oversight Group

BAL: Brooks Applied Laboratories

BT: Brown Trout

CABY: Cosumnes, American, Bear, Yuba Watershed Region

C: Crappie

CC: Channel Catfish

CEDEN: California Environmental Data Exchange Network

CFCP: Coastal Fish Contamination Program

CHHSL: California Human Health Screening Level

CVRWQCB: Central Valley Regional Water Quality Control Board

CWA: Clean Water Act

CDFW: California Department of Fish & Wildlife (formerly Department of Fish & Game)

DCD: Debris Control Dam

DWR: Department of Water Resources

FGC: Fish and Game Commission

FMP: Fish Mercury Project

GS: Green Sunfish

GTLs: Guidance Tissue Levels

Hg: Elemental Mercury

HMF: Hydraulic Mine Feature

LMB: Large Mouth Bass

MeHg: Methylmercury

NFA: North Fork of the American River

OEHHA: California Office of Environmental Health Hazard Assessment

RfD: Reference Dose

RT: Rainbow Trout

RS: Redear Sunfish

RWQCB: Regional Water Quality Control Board

SB: Spotted Bass

SLSFCS: Statewide Lakes Sport Fish Contamination Study

SMB: Small Mouth Bass

SVs: Screening Values

SWAMP: Surface Water Ambient Monitoring Program

SWRCB: California State Water Resources Control Board

TL: Total Length

TSF: The Sierra Fund

TSMP: Toxic Substances Monitoring Program

USEPA: United States Environmental Protection Agency

USGS: United States Geological Survey

WC: White Catfish

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