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Fact Sheet FS-061-00

Mercury Contamination from Historic Gold Mining in California

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Mercury contamination from historic gold mines represents a potential risk to human health and the environment. This fact sheet provides background information on the use of mercury in historic gold mining and processing operations in California, and describes a new USGS project that addresses the potential risks associated with mercury from these sources, with emphasis on historic hydraulic mining areas.

Figure 1. Monitors (water cannons) were used to break down the gold-bearing gravel deposits with tremendous volumes of water under high pressure. Some mines operated several monitors in the same pit. Malakoff Diggings, circa 1860.

Miners used mercury (quicksilver) to recover gold throughout the western United States at both placer (alluvial) and hardrock (lode) mines. The vast majority of mercury lost to the environment in California was from placer-gold mines, which used hydraulic, drift, and dredging methods. At hydraulic mines, placer ores were broken down with monitors (or water cannons, fig. 1) and the resulting slurry was directed through sluices and drainage tunnels, where gold particles combined with liquid mercury to form gold–mercury amalgam. Loss of mercury in this process was 10 to 30 percent per season (Bowie, 1905), resulting in highly contaminated sediments at mine sites (fig. 2). Elevated mercury concentrations in present-day mine waters and sediments indicate that hundreds to thousands of pounds of mercury remain at each of the many sites affected by hydraulic mining. High mercury levels in fish, amphibians, and invertebrates downstream of the hydraulic mines are a consequence of historic mercury use. On the basis of USGS studies and other recent work, a better understanding is emerging of mercury distribution, ongoing transport, transformation processes, and the extent of biological uptake in areas affected by historic gold mining. This information will be useful to agencies responsible for prudent land and resource management and for protecting public health.

Figure 2. Gold pan with more than 30 grams of mercury from 1 kilogram of mercury-contaminated sediments.

Origins of Hydraulic Mining

Vast gravel deposits from ancestral rivers within the Sierra Nevada gold belt contained large quantities of placer gold, which provided the basis for the first large-scale mining in California. Around 1852, hydraulic mining technology evolved, using monitors (fig.1) to deliver large volumes of water that stripped the ground of soil, sand, and gravel above bedrock. The water and sediment formed slurries that were directed through linear sluices (fig. 3) where the gold was recovered. An extensive water transfer system of ditches, canals, and vertical pipes provided the sustained water pressure necessary for hydraulic mining. As mining progressed into deeper gravels, tunnels were constructed to facilitate drainage and to remove debris from the bottom of hydraulic mine pits. The tunnels provided a protected environment for sluices and a way to discharge processed sediments (placer tailings) to adjacent waterways. Hydraulic mines operated on

Figure 3. Gravel deposits were washed into sluices (from center to lower part of figure) where gold was recovered.

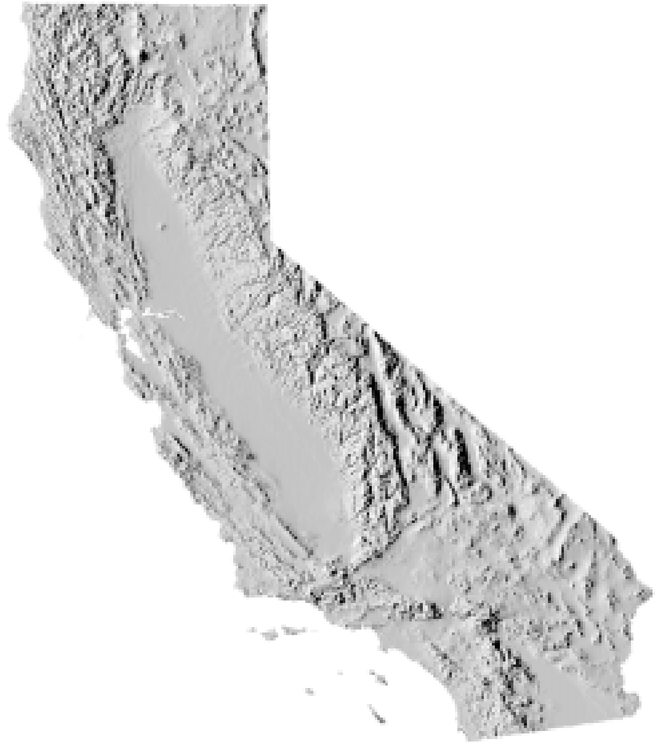
a large scale from the 1850s to the 1880s in California's northern Sierra Nevada region, where more than 1.5 billion cubic yards of gold-bearing placer gravels were worked. In 1884, the Sawyer Decision prohibited discharge of mining debris in the Sierra Nevada region, but not in the Klamath–Trinity Mountains (fig. 4), where hydraulic mining continued until the 1950s. Underground mining of placer deposits (drift mining) and of hardrock gold–quartz vein deposits produced most of California's gold from the mid-1880s to the early 1900s. Dredging of gold-bearing sediments in the Sierra Nevada foothills has been an important source of gold since the early 1900s. Mercury also was used extensively until the early 1960s in the dredging of flood plain deposits, were over 3.6 billion cubic yards were mined. Mercury is recovered today as a by-product from large- and small-scale dredging operations.

Mercury Mining

Most of the mercury used in gold recovery in California was obtained from the Coast Ranges mercury belt on the west side of California's Central Valley (fig. 4). Historic mercury production peaked in the late 1870s (fig. 5). Total mercury production in California between 1850 and 1981 was more than 220,000,000 lb (pounds) (Churchill, 1999). Although most of this mercury was exported around the Pacific Rim or transported to Nevada and other western states, a significant portion (about 12 percent, or 26,000,000 lb) was used for gold recovery in California, mostly in the Sierra Nevada and Klamath–Trinity Mountains.

Mercury Use in Hydraulic Mining

In a typical sluice, hundreds of pounds of liquid mercury (several 76-lb flasks) were added to riffles and troughs to enhance gold recovery. The density of mercury is between that of gold and the gravel slurry, so gold and gold–mercury amalgam would sink, while the sand and gravel would pass over the mercury and through the sluice. Because such large volumes of turbulent water flowed through the sluice, many of the finer gold and mercury particles were washed through and out of the sluice before they could settle in the mercury-laden riffles. A modification known as an undercurrent (fig. 6) was developed to address this loss. Fine-grained sediment was allowed to drop onto the undercurrent, where gold and amalgam were caught. The entire surface of the undercurrent (as much as 5,000 to 10,000 square feet) typically was covered by copper plates coated with mercury.



California. Source: MAS/MILS (Minerals Availability System/ Mineral Information Location System) database compiled by the former U.S. Bureau of Mines, now archived by the USGS.

Gravel and cobbles that entered the sluices caused the mercury to flour, or break into tiny particles. Flouring was aggravated by agitation, exposure of mercury to air, and other chemical reactions. Eventually, the entire bottom of the sluice became coated with mercury. Some mercury escaped from the sluice through leakage into underlying soils and bedrock, and some was transported downstream with the placer tailings. Some remobilized placer sediments remain close to their source in ravines that drained the hydraulic mines. Minute particles of

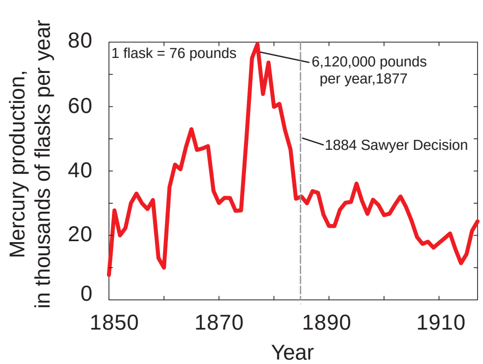


Figure 5. Mercury production from mines in the Coast Ranges of California, 1850-1917 (Bradley, 1918).

Figure 6. Undercurrent in use, circa 1860, Siskyou County, California.

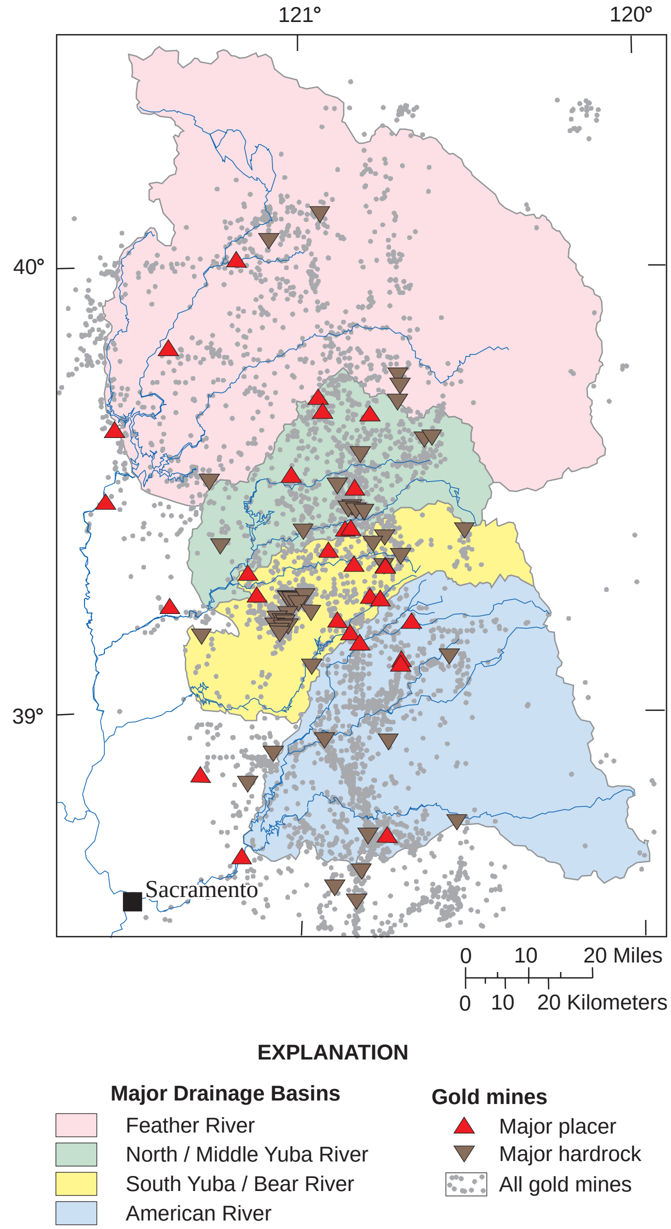


Figure 7. Watersheds in the northwestern Sierra Nevada of California showing past-producing gold mines (as in figure 4) and major placer and hardrock gold mines. Source: USGS KNOWNDEP database (Long and others, 1998).

quicksilver were found floating on surface water as far as 20 miles downstream of mining operations (Bowie, 1905).

Averill (1946) estimated that, under the best operating conditions, 10 percent of the mercury used was lost and, under average conditions, the annual loss of mercury was up to 30 percent. Mercury use varied from 0.1 to 0.36 pounds per square foot of sluice. We estimate that a typical sluice had an area of 2,400 square feet and used up to 800 lb of mercury during initial start-up, after which several additional 76-lb flasks were added weekly to monthly throughout its operating season (generally 6 to 8 months, depending on water availability). Assuming a 10–30 percent loss, the annual loss of mercury from a typical sluice was likely several hundred pounds during the operating season. From the 1860s through the early 1900s, hundreds of hydraulic placer-gold mines operated in the Sierra Nevada. The total amount of mercury lost to the environment from these operations may have been 3–8 million lb or more, from estimates by Churchill (1999) that about 26,000,000 lb of mercury were used in California. Historic records indicate that about 3 million lb of mercury were used at hardrock mines in stamp mills, where ores were crushed. Mercury was also used extensively at drift mines and in dredging operations. The present distribution and fate of the mercury used in historic gold mining operations remains largely unknown, and is the focus of ongoing studies.

The Bear–Yuba Project

The northwestern Sierra Nevada region has been mined extensively for both its hardrock-gold and placer-gold deposits (fig. 7). The American, Bear, Yuba, and Feather River watersheds each have been affected by hydraulic mining. In the northwestern Sierra Nevada, the highest average levels of mercury bioaccumulation occur in the Bear River and South Yuba River watersheds (Slotton and others, 1997). USGS scientists (Hunerlach and others, 1999) have demonstrated a positive correlation of mercury bioaccumulation with intensity of hydraulic gravel mined in the Sierra Nevada (fig. 8). The Bear River and South Yuba River watersheds have been selected by the USGS and federal land management agencies (the Bureau of Land Management and the Forest Service) as well as state and local agencies (see last page) for detailed studies of mercury distribution in relation to historic mine sites. In April 1999, the study team began sampling water, sediment, and biota at mine sites identified as containing mercury “hot spots,” where remediation might reduce risks to human health and the environment. The USGS is also analyzing mercury in sport fish from several lakes and streams in the Bear River and South Yuba River watersheds to allow assessment of potential risks to human health from fish consumption.

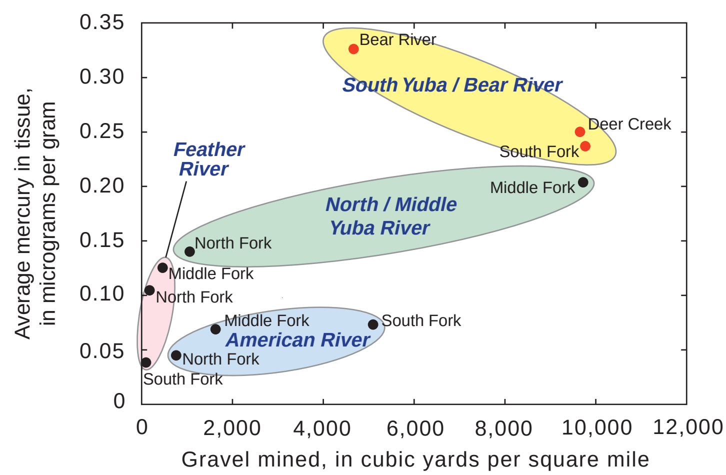


Figure 8. Relationship between intensity of hydraulic mining in Sierra Nevada watersheds and average mercury concentration in tissues of aquatic organisms. Modified from Hunerlach and others (1999). Mercury data from Slotton and others (1997).

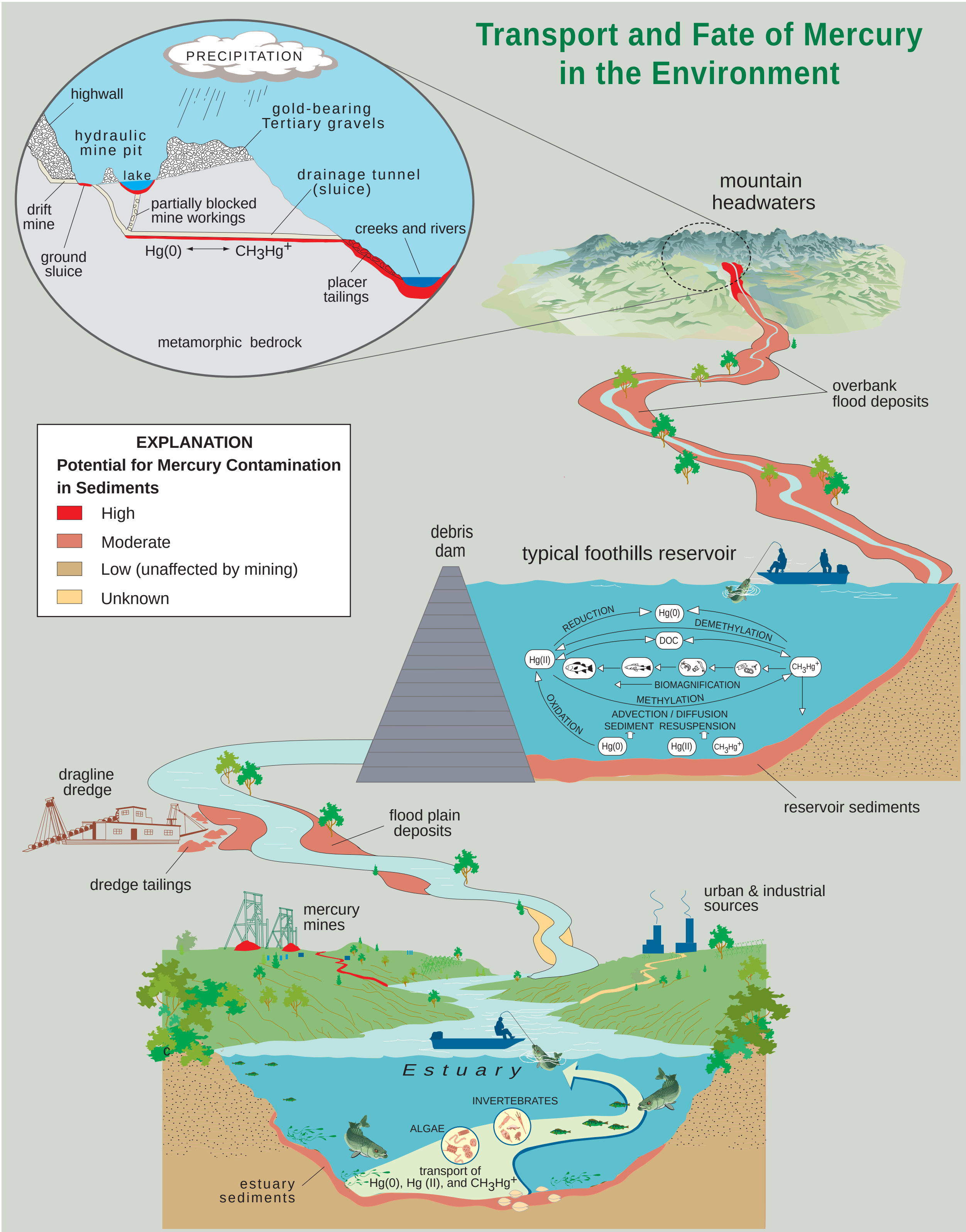


Figure 9. Schematic diagram showing transport and fate of mercury and potentially contaminated sediments from the mountain headwaters (hydraulic and drift mine environment) through rivers, reservoirs, and the flood plain, and into an estuary. A simplified mercury cycle is shown, including overall methylation reactions and bioaccumulation; the actual cycling is much more complex. Hg(0), elemental mercury; Hg(II), ionic mercury (mercuric ion); CH_3Hg^+, methylmercury; DOC, dissolved organic carbon.

MERCURY CONTAMINATION: KEY ISSUES

Risks to Human Health

- Consumption of contaminated fish
- Improper handling of contaminated sediments
- Inhalation of mercury vapors
- Low risk in municipal drinking water
- Some mine waters unsafe for consumption

Challenges for Land Management

- Public access to contaminated areas
- Physically hazardous sites
- Environmental consequences of resource development
- Remediation of affected sites

Environmental Fate of Mercury

- “Hot spots” at mine sites
- Contaminated sediments
- Transport to downstream areas
- Bioaccumulation and biomagnification in food chain

Mercury Methylation and Biomagnification

Mercury occurs in several different geochemical forms, including elemental mercury [Hg(0)], ionic (or oxidized) mercury [Hg(II)], and a suite of organic forms, the most important of which is methylmercury (CH_3Hg^+). Methylmercury is the form most readily incorporated into biological tissues and most toxic to humans. The transformation from elemental mercury to methylmercury is a complex biogeochemical process that requires at least two steps, as shown in figure 9: (1) Oxidation of Hg(0) to Hg(II), followed by (2) Transformation from Hg(II) to CH_3Hg^+; step “2” is referred to as ***methylation****. Mercury methylation is controlled by sulfate-reducing bacteria and other microbes that tend to thrive in conditions of low dissolved oxygen, such as the sediment–water interface or in algal mats. Numerous environmental factors influence the rates of mercury methylation and the reverse reaction known as demethylation. These factors include temperature, dissolved organic carbon, salinity, acidity (pH), oxidation-reduction conditions, and the form and concentration of sulfur in water and sediments.*

The concentration of CH_3Hg^+ generally increases by a factor of ten or less with each step up the food chain, a process known as ***biomagnification****. Therefore, even though the concentrations of Hg(0), Hg(II), and CH_3Hg^+ in water may be very low and deemed safe for human consumption as drinking water, CH_3Hg^+ concentration levels in fish, especially predatory species such as bass and catfish, may reach levels that are considered potentially harmful to humans and fish-eating wildlife, such as bald eagles.*

Fish Consumption Advisories for Mercury

Methylmercury (CH_3Hg^+) is a potent neurotoxin that impairs the nervous system. Fetuses and young children are more sensitive to methylmercury exposure than adults. Methylmercury can cause many types of problems in children, including brain and nervous system damage, retardation of development, mental impairment, seizures, abnormal muscle tone, and problems in coordination. Therefore, the consumption guidelines in areas where CH_3Hg^+ is known to occur in fish at potentially harmful levels tend to be more restrictive for children as well as for pregnant women, nursing mothers, and women of childbearing age.

In the United States, as of 1998, there were a total of 2,506 fish and wildlife consumption advisories for all substances, of which 1,931 (more than 75 percent) were for mercury. Forty states have issued advisories for mercury, and ten states have statewide advisories for mercury in all freshwater lakes and (or) rivers.

In California, as of 1999, there were fish consumption advisories for mercury in 13 waterbodies, including the San Francisco Bay and Delta Region and several areas in the Coast Ranges affected by mercury mining (fig. 10; compare with fig. 4). Data on CH_3Hg^+ levels in fish are presently insufficient for public agencies to determine whether advisories are warranted for lakes and rivers in areas affected by historic gold mining, such as the Sierra Nevada foothills.

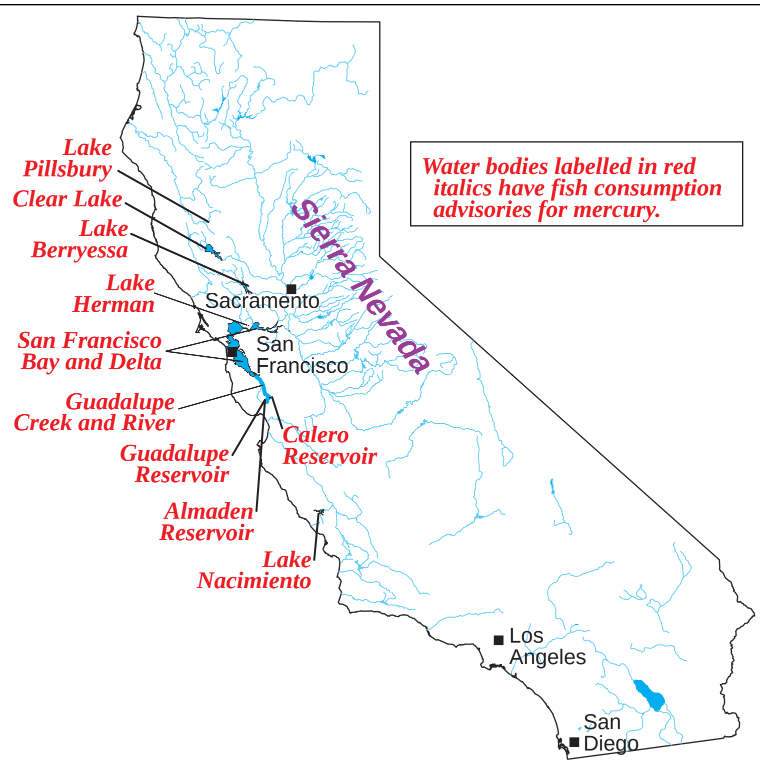


Figure 10. Locations of health advisories for mercury in sport fish consumption in California. Source: California Office of Environmental Health Hazard Assessment, 1999. Lake Pillsbury has interim advisory by Lake County; state advisory pending, as of May 2000.

Lake in hydraulic mine pit caused by blocked drainage tunnel. Acidic water in this pit lake (pH 3.5) caused by oxidation of sulfide minerals in gold-bearing gravel deposits.

Physical hazards at hydraulic mine sites include highwalls (left photo) and open shafts (right photo). Highwalls are steep unstable slopes subject to sudden collapse. Shafts vary from tens to hundreds of feet in depth and connect with horizontal mine workings including drift mines and drainage tunnels.

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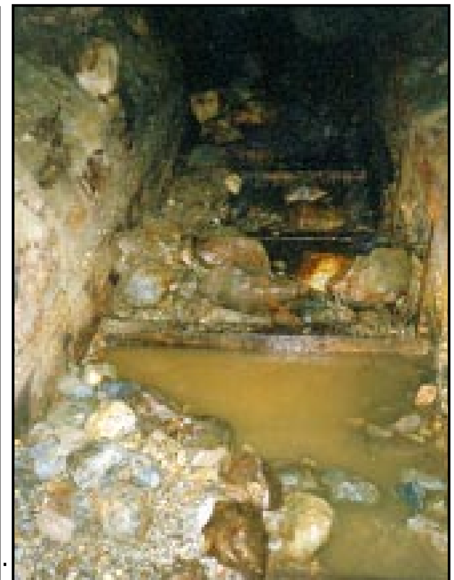

Tunnel sluice with mercury-contaminated sediments.

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http://ca.water.usgs.gov/mercury/
http://mine-drainage.usgs.gov/mine/
http://amli.usgs.gov/amli/
http://www.usgs.gov/

Cooperating Agencies

U.S. Forest Service

California Department of Conservation

California State Water Resources Control Board

Nevada County Resource Conservation District

Bureau of Land Management

U.S. Environmental Protection Agency

California Department of Parks and Recreation