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Western Ecological Research Center
Publication Brief for Resource Managers

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Mercury Cycling and Bioaccumulation in Clear Lake

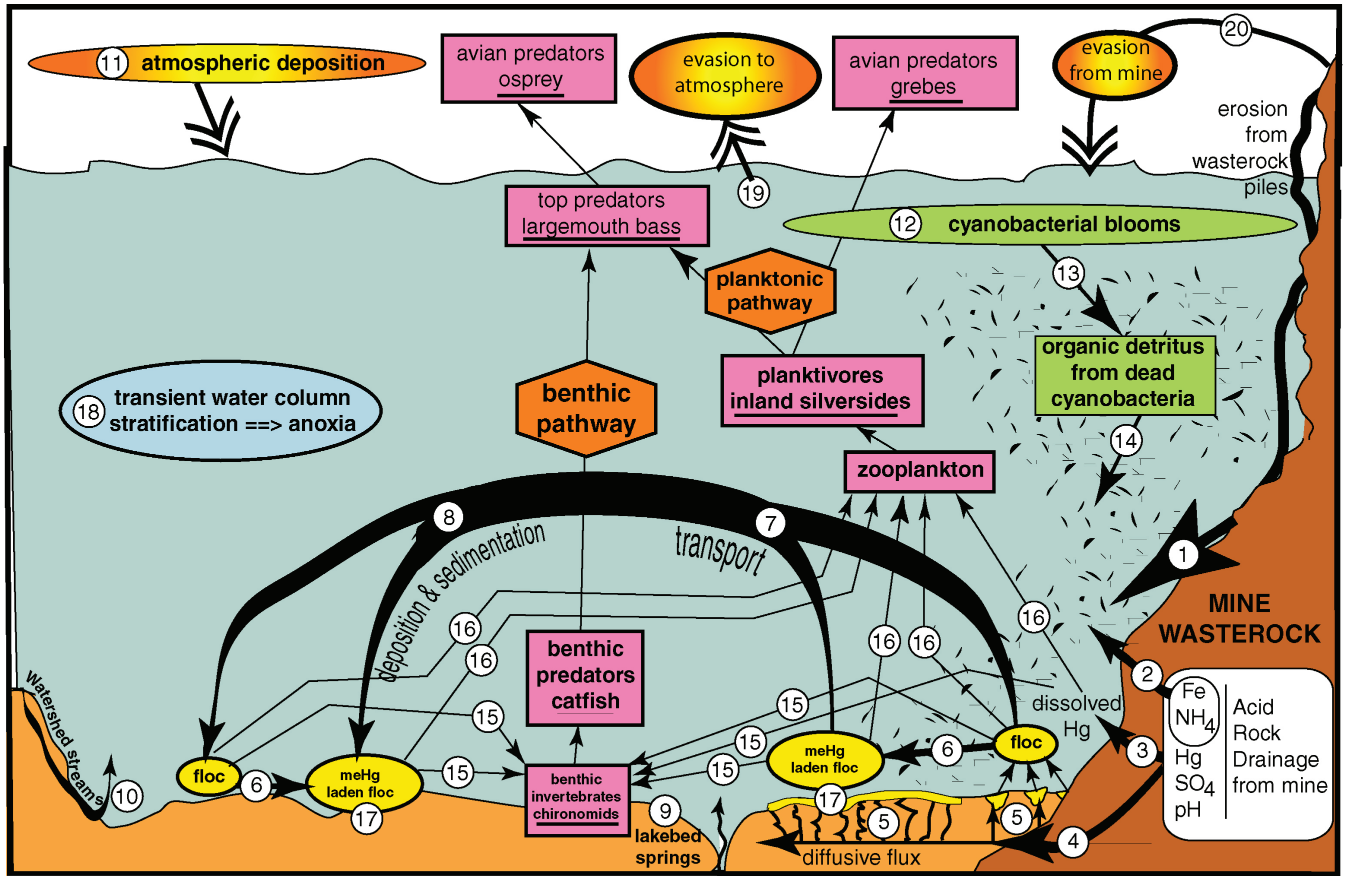
Over the past several decades, most studies of mercury contamination have focused on atmospheric deposition, primarily from coal-fired power plants and a variety of other lesser sources. However, in many regions of the world, mining is the source of significant mercury contamination. Mercury, gold, and silver mining in the western United States, especially in California and Nevada, has contaminated many aquatic ecosystems that support commercial and sport fisheries.

USGS lead scientist on this study, Tom Suchanek, and 28 other scientists from county, state and federal governments and academia have recently released 17 papers in a Special Issue of *Ecological Applications* representing a holistic ecosystem study of the cycling and bioaccumulation of mercury within Clear Lake, California. Clear Lake is the site of the abandoned Sulphur Bank Mercury Mine (active intermittently from 1873-1957), now a USEPA Superfund Site. This mine is one of nearly 300 abandoned mercury mines and prospects along the Coast Range of California. Mining activities, including bulldozing waste rock and tailings into the lake, resulted in ca. 100 metric tons of mercury entering the lake's ecosystem. This study represents the culmination of ca. 15 years of research, following mercury from the ore body, through the lake, and into the highest trophic levels, including predatory fish and birds. A series of inter-disciplinary physical, chemical, biological, and limnological studies elucidate how ongoing mercury loading to the lake from the mine is influenced by acid mine drainage and other chemical and biological factors and how wind-driven currents and baroclinic circulation patterns redistribute mercury throughout the lake. Formation of toxic methylmercury is facilitated in this system by both sulfate-reducing bacteria as well as newly identified iron-reducing bacteria. Sediment cores elucidate a record of total mercury loading to the lake from natural and human sources and demonstrate how methylmercury remains stable at depth within the sediment column for decades to millenia. Core data also identify other stresses that have influenced the Clear Lake Basin especially over the past 150 years.

Management Implications:

- Mercury derived from mining sources exhibits very different cycling and bioaccumulation characteristics than mercury derived from atmospheric deposition (which is typically from coal-fired power plants).
- Mercury contamination derived from cinnabar mercury mine sites has the potential to produce highly contaminated biota, including fish species that are consumed by wildlife and humans.
- In highly mercury-contaminated lakes, methylmercury can remain stable at depths within the sediment column for decades to millenia and thus could be redistributed throughout the ecosystem by significant dredging.
- Water, sediments, and biota from mercury mining sites may exhibit lower methylmercury concentrations than would be expected based on levels of bulk inorganic mercury loading.

Based on a mass balance mercury budget calculation (Suchanek et al. 2009), Clear Lake is one of the most mercury-contaminated lakes in the world, with the abandoned mine contributing an ongoing loading of ca. 325 kg of mercury to the lake each year. Critical water and sediment quality criteria for total mercury at Clear Lake are exceeded at most sites and most seasons, although biota do not exhibit methylmercury concentrations as high as would be predicted based on the gross level of total mercury loading. We compare Clear Lake's total mercury and methylmercury concentrations with other sites worldwide and suggest several hypothe-



Conceptual model of pathways and processes involved in mercury cycling in Clear Lake. Model: T.H. Suchanek, USGS. Key for numbered pathways: 1) Surface erosion of ARD (Acid Rock Drainage) producing particulate and dissolved Hg (mercury) from waste rock and tailings; 2) Subsurface ARD flow into the water column yielding particulate Hg, Fe (iron) and NH_4 (ammonium) to the near-shore environment; 3) Subsurface ARD flow into the water column yielding dissolved Hg, SO_4 (sulfate) and acidic fluids to the near-shore environment; 4) Sub-sediment lateral diffusive flow that moves ARD far out into the Oaks Arm of Clear Lake; 5) Upward advection of ARD to the sediment/water interface and production of floc (a white precipitate created when pH3 acidic fluids from the mine mix with pH8 water in Clear Lake); 6) Transformation of inorganic Hg to MeHg (methylmercury); 7) Transport of inorganic Hg and MeHg on floc particles to other regions of Clear Lake; 8) Deposition of products from #7 onto sediments in other regions of Clear Lake; 9) Input of fluids from lakebed springs; 10) Input of Hg from watershed streams; 11) Input of Hg from wet and dry atmospheric deposition onto the lake surface; 12) Seasonal production of cyanobacteria blooms; 13) Degradation of cyanobacteria blooms to produce organic detritus source; 14) Utilization of cyanobacterial organic detritus by SO_4^- and Fe^- bacteria that methylate Hg; 15) Bioaccumulation of Hg via benthic pathway; 16) Bioaccumulation of Hg via planktonic pathway; 17) Long-term burial of Hg in sediments; 18) Transient water column stratification drives anoxic conditions stimulating methylation; 19) Evasion of Hg from the lake surface to the atmosphere; 20) Evasion of Hg from mine site and redeposition onto the lake surface.

ses to explain why this discrepancy exists. Based on our data, together with state and federal water and sediment quality criteria, we predict potential resulting environmental and human health effects and provide data that can assist remediation efforts.

Suchanek et al. 2008. Mercury Cycling and Bioaccumulation in Clear Lake. Ecological Applications Special Issue—Supplement 18(8): 297 pp.
(This volume is accessible at: http://www.esajournals.org/toc/ecap/18/sp8)

Suchanek, T.H., J. Cooke, K. Keller, S. Jorgensen, P.J. Richerson, C.A. Eagles-Smith, E.J. Harner, and D.P. Adam. 2009. A mass balance mercury budget for a mine-dominated lake: Clear Lake, California. Water, Air and Soil Pollution 196(1):51-73.