Executive Summary

Methylmercury Production, Export, and Water Quality Transformation in Lake Almaden: Implications for Management

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Background

Lake Almaden is a small reservoir located along Alamitos Creek in Santa Clara County, California, within the approximately 170-square-mile Guadalupe River Watershed (SFRWQCB, 2008b). Originally formed from a flooded gravel quarry in the mid-20th century, the lake now serves as a recreational resource and provides habitat for fish and wildlife (ESA, 2021). Despite its modest size, Lake Almaden plays an important role in regional water quality due to its connection to legacy mercury contamination from the nearby New Almaden Mining District. Historical mining operations released large quantities of mercury into the surrounding landscape, and these contaminants continue to be transported downstream in sediments and runoff (Austin, 2022; Mindat, 2026; SCCP, n.d.; Figure 1).

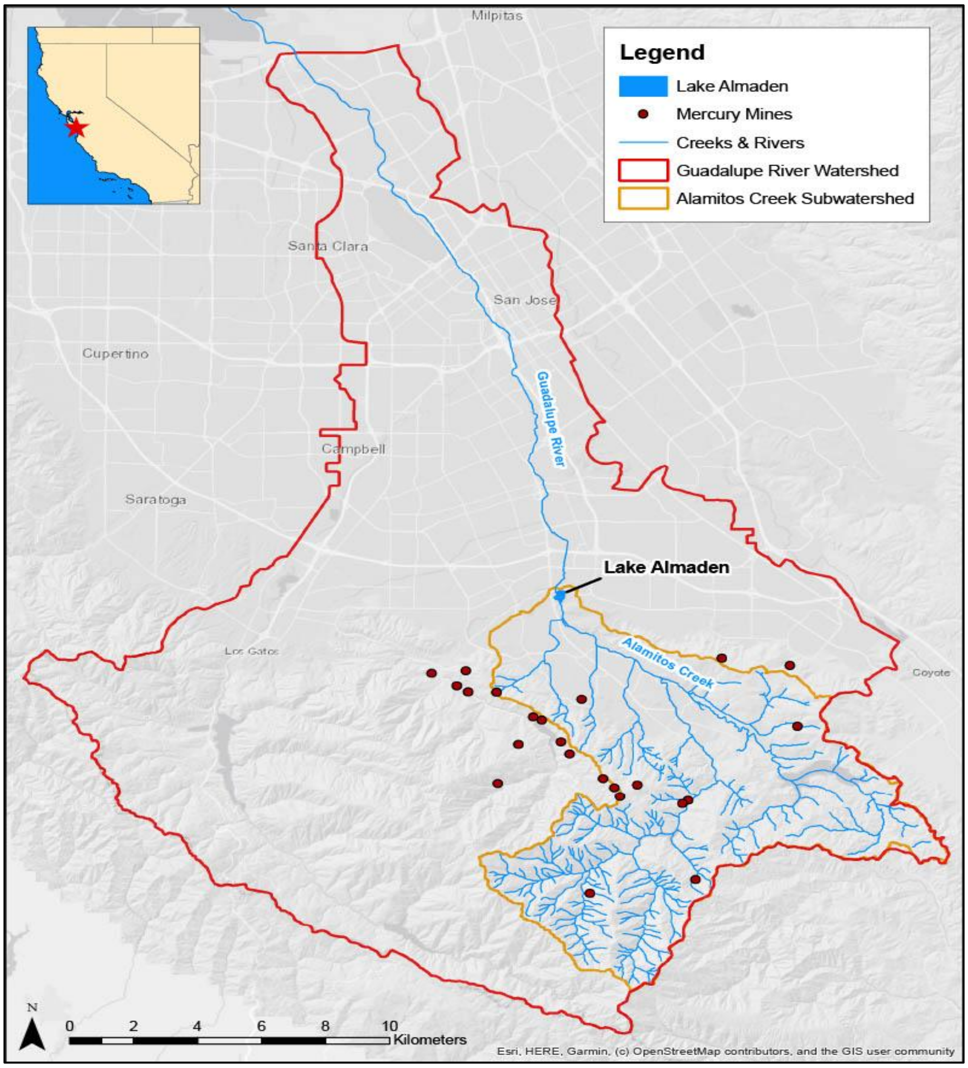

Figure Error! No text of specified style in document.**.** Location of Lake Almaden within the Guadalupe River watershed (170 mi^2) and the Alamitos Creek subwatershed (38 mi^2) in Santa Clara County, California, and proximity to legacy mercury mining sites in the New Almaden Mining District. Map created using spatial data provided by Valley Water (2025).

Once in aquatic systems, inorganic mercury can be transformed into methylmercury (MeHg), a highly toxic and bioaccumulative form that poses risks to fish, wildlife, and human health (Seelos et al., 2022). This transformation is primarily driven by anaerobic microorganisms under low-oxygen conditions, particularly in stratified systems where vertical mixing is limited due to water temperature gradients (Gilmour et al., 2013; Parks et al., 2013; Ullrich et al., 2001). Lake Almaden's eutrophic conditions, long residence time, and seasonal stratification create an environment well suited for these processes. During stratification, a distinct thermocline and associated oxycline develop, isolating bottom waters and promoting low-oxygen conditions favorable for methylation (Figure 2). As a result, the lake functions not only as a transport pathway for mercury, but also as an active site of MeHg production and cycling.

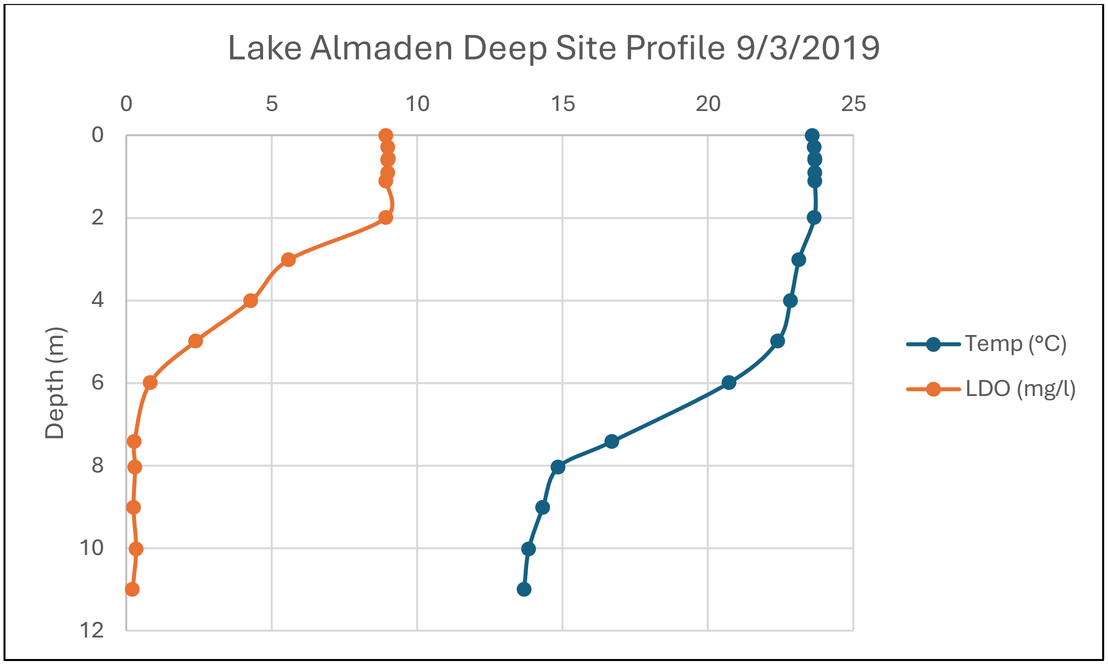

Figure 2. Vertical sonde profile at the deep site highlighting the thermocline and oxycline that develops during summer stratification.

Mercury contamination in the Guadalupe River Watershed is formally recognized as a major water quality impairment under the EPA's Clean Water Act. In response, the San Francisco Bay Regional Water Quality Control Board adopted the Guadalupe River Watershed Mercury Total Maximum Daily Load (TMDL) in 2008, establishing regulatory targets for mercury in water, sediment, and fish tissue (SFRWQCB, 2008a). These efforts are supported by coordinated monitoring programs led by the Santa Clara Valley Water District (URS, 2012; Tetra Tech, 2024).

Beyond mercury, Lake Almaden presents broader water quality and ecological challenges. Thermal stratification and long residence time contribute to elevated temperatures, algal growth, and turbidity, while also degrading habitat for native species such as steelhead trout (*Oncorhynchus mykiss*) (ESA, 2021). Together, these factors highlight the dual role of Lake

Almaden as both a site of contaminant transformation and a driver of downstream water quality impacts.

Purpose

This study evaluates how water quality changes as water passes through Lake Almaden, with a primary focus on MeHg dynamics and key physical and biological indicators. While mercury contamination in the watershed has been studied extensively, less attention has been given to how in-lake processes influence mercury transformation and downstream export along the inlet-to-outlet flow path.

To address this gap, this study integrates long-term monitoring data collected between 2005 and 2025, including both grab samples and sonde measurements from the lake's inlet, outlet, and deepest point. This approach allows for an assessment of how stratification, redox conditions, and biological activity interact to influence MeHg production and overall water quality.

The primary objective is to determine whether Lake Almaden functions as a net source of MeHg to the downstream Guadalupe River, particularly during stratified periods. In addition, this study evaluates how water quality parameters, including temperature, algal biomass, and turbidity, change as water moves through the lake and how observed MeHg concentrations compare to TMDL targets (SFRWQCB, 2008a).

Methods

Data were compiled from Valley Water's monitoring program and span a 20-year period (2005–2025). The dataset includes both laboratory-analyzed grab samples and in situ measurements collected using multiparameter sondes at three primary locations: the lake inlet, outlet, and deepest point. Grab samples were collected monthly to quarterly and analyzed for MeHg using EPA Method 1630, following strict clean sampling protocols to minimize contamination (EPA, 1996). A total of over 600 MeHg samples were included in the analysis. Sonde measurements provided depth-specific data on key water quality parameters, including temperature, dissolved oxygen, chlorophyll *a*, phycocyanin, and turbidity.

To evaluate the role of in-lake processes, analyses focused on stratification dynamics and inlet-to-outlet comparisons. Thermal stratification was classified using the temperature difference between surface and bottom waters, with strongly stratified conditions defined by a difference greater than 4°C. Hypoxia was defined as dissolved oxygen concentrations at or below 1 mg/L, representing conditions that promote anaerobic microbial activity associated with MeHg production (Gilmour et al., 1992; Eckley & Hintelmann, 2006).

Key Findings

Results from this study show that Lake Almaden plays an active role in both MeHg production and downstream water quality transformation, with patterns observed across stratification dynamics, inlet–outlet comparisons, and long-term trends.

First, strong evidence supports that MeHg production is closely linked to thermal stratification and hypolimnetic hypoxia. During stratified conditions, hypolimnetic MeHg concentrations were approximately five times higher than during mixed conditions (7.35 vs. 1.48 ng/L; $p = 2.25 \times 10^{-12}$). Similarly, hypoxic conditions were associated with over an eight-fold increase in MeHg compared to oxic conditions (5.45 vs. 0.65 ng/L; $p < 2.2 \times 10^{-16}$). Stratification strength and dissolved oxygen each explained a substantial portion of MeHg variability ($r^2 = 0.34$ and 0.30, respectively), indicating that both physical and redox conditions are key controls on MeHg production. These findings are consistent with well-established mechanisms of microbial methylation under low-oxygen conditions (Gilmour et al., 2013; Ullrich et al., 2001). These differences are clearly illustrated in Figures 3 & 4, which shows substantially higher hypolimnetic MeHg concentrations during stratified and hypoxic conditions.

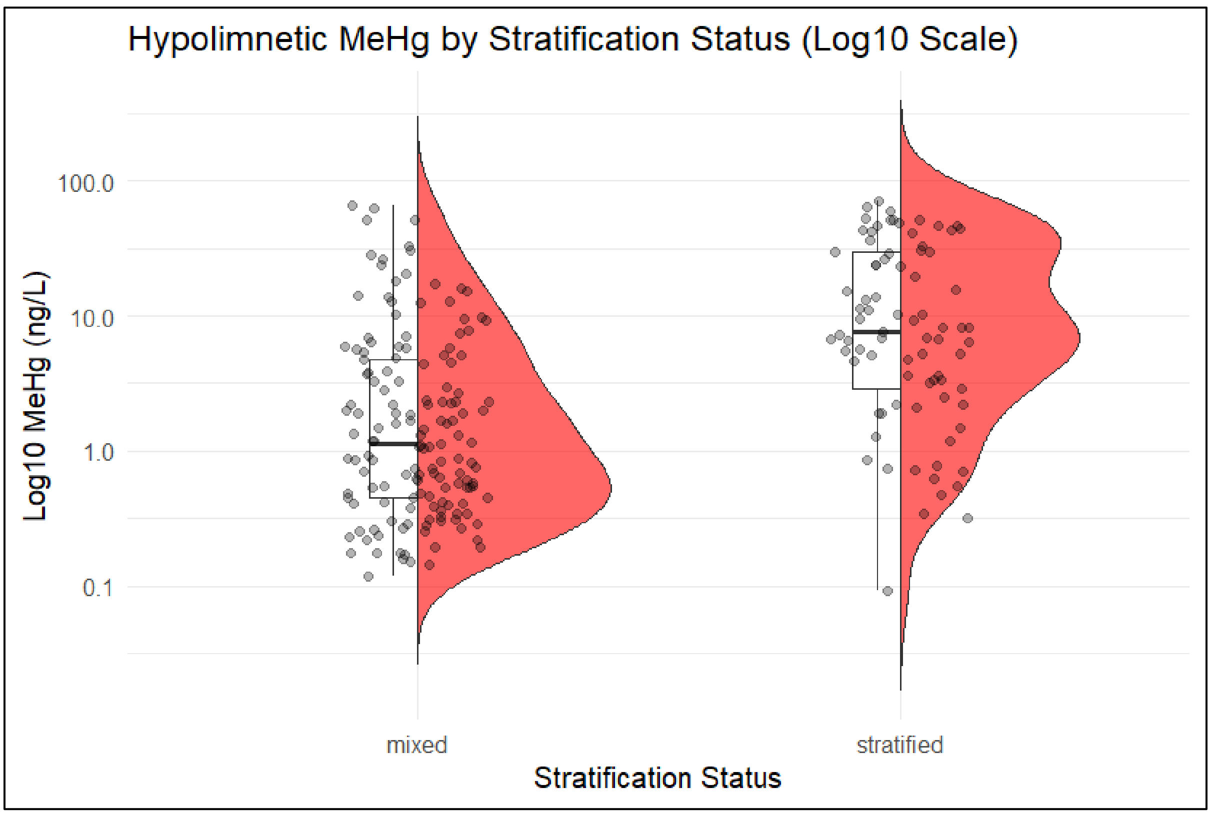

Figure Error! No text of specified style in document.**.** Hypolimnetic MeHg concentrations increase 5× during stratification

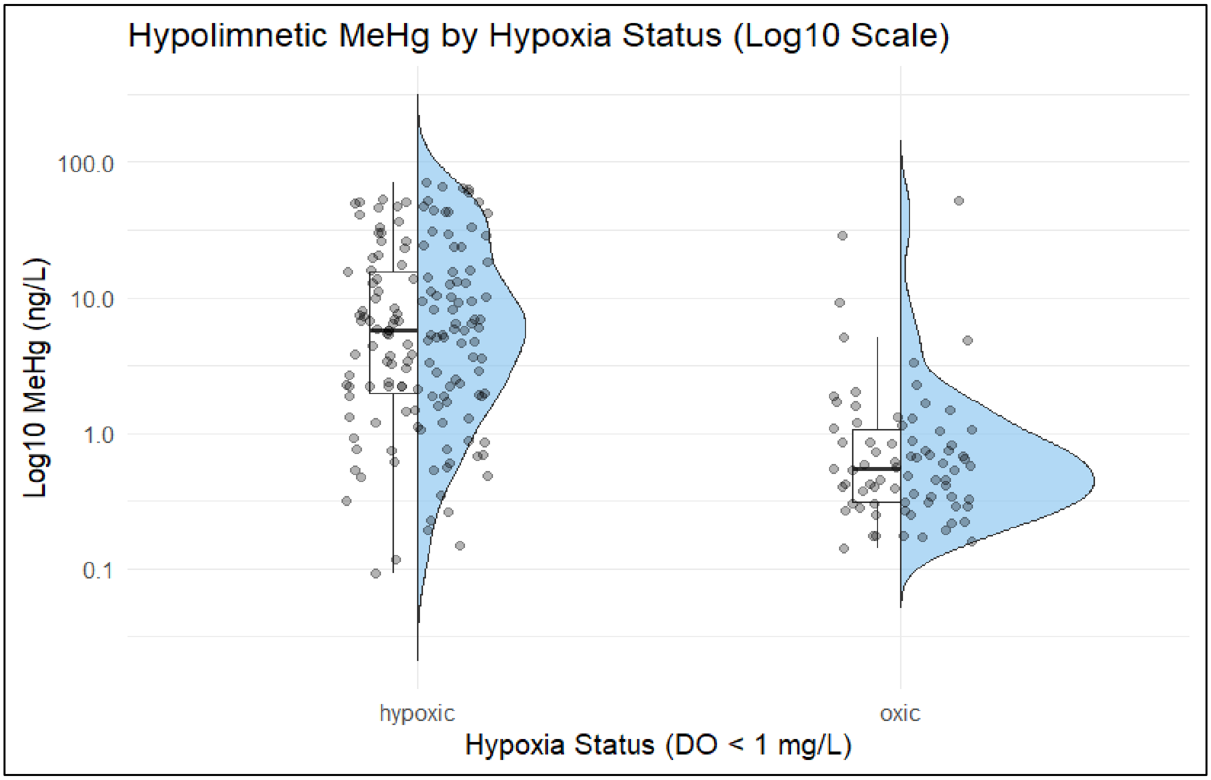

Figure 4. MeHg concentrations increase 8.3× under hypoxic conditions.

Second, Lake Almaden generally functions as a net source of MeHg to the downstream Guadalupe River (Figure 5). Across 175 paired inlet–outlet samples, MeHg concentrations at the outlet were significantly higher than at the inlet under both mixed and stratified conditions. On average, outlet concentrations were approximately 47% higher during mixed periods and 50% higher during stratified periods ($p < 0.001$). While stratification slightly increased the magnitude of export, the difference between conditions was modest, suggesting that the lake frequently exports MeHg regardless of stratification state. This pattern is likely influenced by the lake's hydrology, where surface level outflow can limit the direct export of concentrated MeHg hypolimnetic waters until seasonal mixing redistributes water upwards. Long-term analysis further indicates that MeHg export is frequent with export occurring in 126 of 175 sampling events. As shown in Figure 5, most sampling events resulted in positive outlet–inlet differences, indicating regular downstream export of MeHg through time.

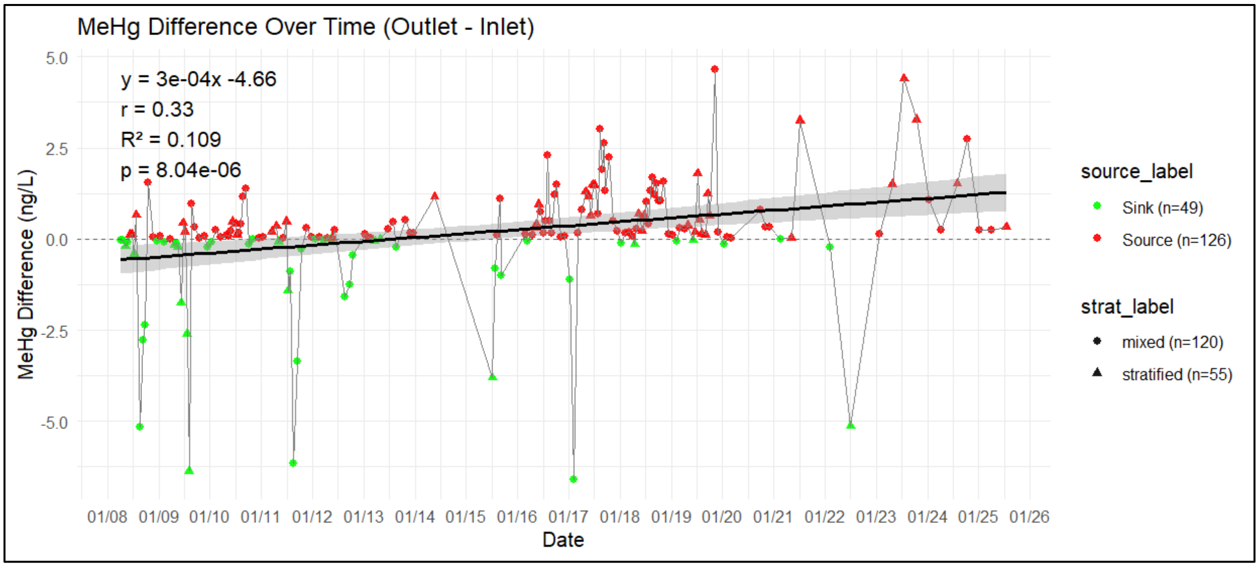

Figure 5. Lake Almaden frequently exports MeHg downstream.

In addition to mercury dynamics, water quality consistently degraded as water passed through the lake. Surface water temperature increased by an average of 7%, while indicators of biological productivity showed substantial increases, including a 138% rise in chlorophyll a and a 78% increase in phycocyanin. Turbidity also increased by 39%, reflecting reduced water clarity. All of these changes were statistically significant ($p < 0.001$) and demonstrate that Lake Almaden alters not only contaminant dynamics but also broader physical and ecological conditions.

Importantly, observed MeHg concentrations frequently exceeded regulatory targets established under the Guadalupe River Watershed Mercury TMDL. Mean hypolimnetic MeHg concentration during stratified periods was approximately 7.35 ng/L, which is nearly five times higher than the maximum target of 1.5 ng/L (SFRWQCB, 2008a). Even during mixed conditions, concentrations approached this benchmark. Combined with the frequent pattern of downstream export, these findings indicate that Lake Almaden remains a persistent and active source of bioavailable mercury within the watershed.

Overall, the results demonstrate that Lake Almaden is not simply a passive system but a dynamic environment where stratification, redox conditions, and biological productivity interact to drive MeHg production, water quality degradation, and downstream transport.

Management Implications

Hydraulic separation of Alamitos Creek from Lake Almaden represents the most direct long-term strategy. Disconnecting the creek would prevent water from entering a warm, nutrient-rich, and seasonally hypoxic environment that promotes MeHg production, while also improving habitat connectivity and restoring more natural stream processes (ESA, 2021). Although implementation has been delayed, the magnitude of MeHg production and export observed in this study suggests that this approach remains a high priority.

However, separation alone would not address internal lake processes. Hypolimnetic oxygenation offers a targeted strategy to reduce MeHg production by increasing dissolved oxygen and limiting anaerobic microbial activity. Among available technologies, Side-Stream Supersaturation (SSS) is particularly promising because it increases oxygen without disrupting stratification, reducing the risk of algal blooms and internal nutrient cycling (Gerling et al., 2014; Preece et al., 2019).

Together, these strategies provide a combined approach that reduces external exposure pathways through hydraulic separation while addressing internal biogeochemical processes through targeted oxygenation.

Conclusion

This study evaluated how water quality changes as water moves through Lake Almaden, with a focus on MeHg production, transport, and associated physical and biological processes. By integrating long-term monitoring with sonde measurements, this work addressed a key gap in understanding how in-lake dynamics influence downstream water quality, particularly along the inlet-to-outlet flow path, which is not fully captured in current routine monitoring efforts.

Overall, results show that Lake Almaden functions as an active site of mercury transformation rather than a passive conduit. Thermal stratification and hypolimnetic hypoxia were identified as dominant controls on MeHg production, creating conditions that strongly enhance in-lake methylation. As a result, MeHg concentrations frequently increased as water moved from the inlet to the outlet, indicating that the lake functions as a net source of MeHg to the downstream Guadalupe River.

Beyond mercury, Lake Almaden also alters broader water quality conditions. Surface water warms, algal and cyanobacterial biomass increase, and turbidity rises as water passes through the system. These changes reflect longer residence time and enhanced biological productivity, and they are directly linked to mercury cycling through their influence on oxygen depletion and microbial activity.

From a regulatory perspective, MeHg concentrations frequently exceeded targets established under the Guadalupe River Watershed Mercury TMDL (SFRWQCB, 2008a), reinforcing the role of Lake Almaden as a persistent source of bioavailable mercury. These findings help explain ongoing challenges in meeting watershed-scale management goals and highlight the importance of incorporating inlet–outlet dynamics into monitoring and assessment frameworks.

Overall, this study demonstrates that internal lake processes are central to understanding and managing mercury impairment. By linking stratification, redox conditions, and biological activity to MeHg production and export, this study provides a clear foundation for targeted management actions. Addressing these in-lake drivers will be critical for reducing downstream mercury exposure and achieving long-term water quality goals in the Guadalupe River Watershed.

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