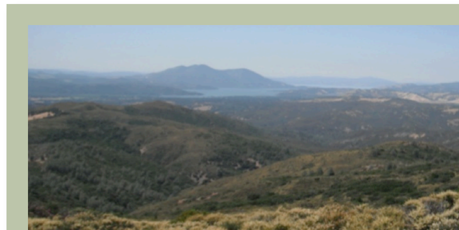
Recommendations

To decrease mercury loads in the Basin and to meet TMDL requirements, remediation and restoration actions must take place, as well as additional actions to reduce erosion and the transport of mercury. As written in the Basin Plan (CVRWQCB, 2009), it is the responsibility of the BLM and other liable parties to reduce mercury concentrations to background levels, even if restoration actions may not meet water quality objectives. As the largest land manager in the mining region, the BLM is in a position to influence the overall management of the area. They can reduce mercury loads and improve the state of knowledge about mercury sources and conditions.

The recommendations for the BLM can be grouped into four categories:

1) **Actions to take**: Remediation and restoration actions as well as best management practices that can be implemented in the region,
2) **Additional data collection**: More water quality samples to understand mercury sources and continued water quality monitoring before and after remediation and restoration actions,
3) **Further research**: More sponsorship of applied research into methylation processes, better mercury sources and concentrations, and remediation and restoration options, including emerging technologies,
4) **Partnerships**: Collaborations BLM can encourage with other agencies and entities to help reduce mercury pollution within the Basin and downstream.



Under the Federal Land Protection Management Act (FLPMA), the Bureau of Land Management's responsibility is to "provide the public the opportunity to use and appreciate significant cultural and natural resources while protecting and conserving them."

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Conclusion

Our project focused on assisting with decision making surrounding remediation and restoration efforts in the Cache Creek Basin. We developed decision trees and a ranking system to provide a framework for BLM staff and others to begin the restoration and remediation process. These tools provide a structured approach to addressing a daunting pollution issue, and allow the user to determine a remediation method that best suits specific environmental parameters of a site, as well as other key considerations, such as cost. Mercury pollution is not unique to the Cache Creek Basin, and our trees and ranking system are meant to provide a framework that can be applied to other locations with mercury contamination issues.

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Photos of Cache Creek Basin by Kristiana Teige; Map by Nick Zigler

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PROJECTBRIEF

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Strategies to Control Mercury Pollution in the Cache Creek Basin, Northern California

Background

The Cache Creek Basin, located in Northern California, is one of the major contributors of mercury to the Sacramento-San Joaquin Delta and San Francisco Bay. Sources of mercury to the Cache Creek Basin include geothermal springs, erosion of natural mercury-enriched soils, atmospheric deposition, sediment enriched with legacy mercury, as well as waste rock and tailings from historical mines. Mercury mining in the region began in the mid-nineteenth century to assist with gold extraction from ore during the California Gold Rush. At the time, little was understood about the toxicity of mercury. Highly erodible waste rock and tailings containing elevated concentrations of mercury were left on steep slopes near tributaries of Cache Creek. Rainfall and resulting erosion caused the tailings to accumulate as sediment in creek beds, some of which then flows into the Sacramento River and Sacramento-San Joaquin Delta.

Mercury pollution in this region is a concern because of the impacts mercury toxicity can have on human health and wildlife. Developing organisms and children are particularly susceptible to the neurotoxic effects of mercury (Alpers et al., 2008; USEPA, 2001). In addition, mercury is able to bioaccumulate within organisms and biomagnify as it transfers to higher trophic levels within food webs. According to Domagalski et al. (2004), "the bioaccumulation of mercury in fish is one of the most widely recognized environmental problems of the current era."

Cache Creek Basin Facts

- Area: 2,978 km^2
- Upper part within California Inner Coast Ranges; lower part within Sacramento Valley
- Elevation from 8 to 1,815 meters (mostly 300 to 800 meters)
- Water uses: Wildlife, irrigation, municipal, recreation (fishing, kayaking)
- BLM manages 26% of Cache Creek Basin
- 110 km^2 Cache Creek Wilderness
- 16 mercury mines

Project Objectives

1) Identify ways to conduct mercury remediation and restoration in Cache Creek Basin,
2) Develop a method to determine best remediation and restoration options for different site locations,
3) Evaluate management options through watershed modeling,
4) Assess legal constraints on management options.

In order to address mercury problems in the Cache Creek Basin, The Environmental Protection Agency (EPA) and the Central Valley Regional Water Quality Control Board (CVRWQCB) have established maximum mercury concentration levels or Total Maximum Daily Load (TMDL) for both water and biota. Currently, these levels are being exceeded within the Cache Creek Basin, and remediation and restoration actions will be necessary to meet water quality objectives. Our client, the Bureau of Land Management (BLM) manages approximately 300 square miles of the Cache Creek Basin, and has significant interest in controlling mercury diffusion from abandoned mine lands and the mercury that has accumulated in the sediments downstream of these lands. The BLM and other landowners have initiated cleanup efforts at some of the abandoned mine sites, but further action will be needed to meet water quality goals. The objectives of this project were to provide a structured approach to analyzing the mercury contamination in the area, assess the effectiveness of different remediation techniques, and to aid in bridging gaps of knowledge about mercury contamination issues in the Basin.

Methodology

We developed a series of decision trees in order to aid the BLM with the process of gathering information about management decisions for potential remediation or restoration actions. The first decision tree guides decision makers as they determine site-specific characteristics that may impact the types of management actions taken at a site or if restoration and remediation efforts should be focused on an alternate site. The second decision tree is used to determine possible remediation actions for a specific site. There are a wide variety of technologies and management options that can be use to control mercury contamination. These range from high impact, high cost technologies, such as excavation to low footprint, low cost technologies, such as phytoremediation. Finally, the third decision tree guides the decision maker in gathering information about the cost, effectiveness, and time frame for selected management actions.

After the most applicable remediation technologies are determined through the use of the decision trees, the options can be ranked. Options are ranked based on relative cost, effectiveness, and time frame to clean up a site. Ranked scores can be adjusted in order to emphasize the varying levels of importance a decision maker may place on these parameters. In order to illustrate the use of the decision trees and ranking system, we evaluated six sites with varying physical attributes as case studies. Each site was characterized using the first decision tree and applicable restoration and remediation actions were chosen based on the second and third decision trees. Each applicable option was ranked from the perspective of a decision maker that puts more emphasis on health effects and may choose technologies with higher efficiencies, as well as a decision maker that puts more emphasis on low budget technologies.

In addition to creating a decision-making framework, we used WARMF (Watershed Analysis Risk Management Framework), a watershed modeling program, to examine the fate and transport of mercury

in the Basin. WARMF can be used to track changes in water quality parameters through time and explore the effects of reducing contaminant loads from point and nonpoint sources within a watershed. It has been used to evaluate management options for other TMDLs and is one of the few watershed models that include parameters for mercury.

Case Studies Results

- Low budget emphasis: Phytoremediation most frequently recommended
- More effective technology emphasis: Excavation most frequently recommended

Watershed Model Results

- Removal of all mines: 11% reduction in mercury loads
- Only 1 of 4 mercury concentration levels will likely be met within the Basin
- Mercury loads within the Basin may have been overestimated by a factor of two

Results: Case Studies Summary

Although restoration options are site-specific, some trends emerged from the case studies regarding recommended management options. When management options were ranked with a low budget emphasis, phytoremediation was the most frequently recommended option, while excavation was the most frequently recommended strategy when emphasizing more effective reduction of mercury contamination.

The decision trees are meant to serve as a starting point for BLM staff to gather the basic information necessary to prioritize sites for cleanup and begin restoration or remediation activities. We attempted to generalize the decision process in a way that would facilitate a wider applicability not only across the entire Cache Creek Basin, but in other locations where legacy mercury pollution exists.

Results: Watershed Model Summary

Using WARMF, we simulated the remediation of all mines in the basin by removing them as point sources. It was found that mercury loads from the Basin are reduced by 11% with the removal of all mines. This indicates that there is a significant amount of mercury originating from other sources, such as legacy mercury in stream sediments along Cache Creek or from natural sources located within the Cache Creek Canyon area.

The TMDL for Harley Gulch (Cooke et al., 2004; Cooke and Morris, 2005) is unlikely to be met, because of the naturally elevated mercury concentrations in the region. However, the TMDL for Sulphur Creek (Cooke and Stanish, 2007) has much lower standards than the Harley Gulch TMDL, due mostly to the acknowledgement of the high mercury contribution from thermal springs during the dry season, and will most likely be met. The TMDL for Bear Creek (Cooke et al., 2004; Cooke and Morris, 2005) is also unlikely to be met, due to high mercury concentrations in the region just upstream of Sulphur Creek as well as the high mercury concentrations from Sulphur Creek. It is unknown whether the TMDL for Cache Creek (Cooke et al., 2004; Cooke and Morris, 2005) will be met, and depends to a large extent on whether methylation in Clear Lake can be reduced.

According to our model, mercury loads within the basin may have been overestimated by a factor of two. This has implications for the Sacramento-San Joaquin Delta Estuary TMDL (Wood et al., 2008) because the Cache Creek may not be as large of a mercury source as previously assumed. This may make it more difficult to reduce mercury in the Delta because remediation and restoration actions completed in the Basin will not have as much of an impact as predicted on mercury loads reaching the Delta from the Sacramento River and Yolo Bypass.