STRATEGIES TO CONTROL POLLUTION FROM MERCURY AND OTHER SUBSTANCES IN THE CACHE CREEK BASIN, INNER COAST RANGE, NORTHERN CALIFORNIA

A 2011 Group Project Proposal

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ABSTRACT

The Cache Creek Basin in Northern California provides a number of beneficial uses for both humans and wildlife. Water from Cache Creek is used for a variety of purposes including water for drinking and irrigation, habitat for wildlife, fishing, and other recreational activities such as kayaking and rafting. However, in addition to these benefits, Cache Creek contains high levels of mercury pollution originating from abandoned mine lands as well as from natural sources such as geothermal springs. This mercury has adverse health effects for both humans and wildlife in the Cache Creek Basin, downstream in the Sacramento River, the San Francisco Bay Delta, and the San Francisco Bay. The Central Valley Regional Water Quality Control Board (CVRWQCB) has established Total Maximum Daily Load (TMDL) requirements for mercury within the Cache Creek Basin; the Bureau of Land Management (BLM), which manages 300 square miles of the Basin, must try to meet these requirements. The objective of this project is to assist the BLM with determining the most effective mercury management strategies to meet this goal, which may include new and innovative strategies that have not been attempted in previous remediation efforts. In order to achieve this goal, we will evaluate the effectiveness of various applicable remediation strategies, analyze these strategies using a computer model, provide a cost benefit analysis of these strategies, and present a policy analysis of the role of each of the parties involved and the environmental regulations they are subject to.

EXECUTIVE SUMMARY

The Bureau of Land Management is responsible for managing approximately 300 square miles of the Cache Creek Basin in northern California. One of the main challenges faced by the BLM in this watershed is the proper management of elevated levels of mercury in the water and wildlife that have resulted from mercury runoff from abandoned mine lands. It is the duty of the BLM to “maintain the health of the land and to the best of its ability to restore or replace resources that are harmed by pollution” (BLM, 2008). The BLM must develop effective management strategies in order to preserve the beneficial uses in the watershed as well as protect the health of both humans and wildlife. Some remediation efforts have already been conducted in order to meet TMDL requirements established by the CVRWQCB, but many questions still remain. The objective of this project is to make recommendations to the BLM about the most effective cleanup solutions for the mercury pollution from abandoned mines and the sediment downstream of the mines in order to meet TMDL requirements. These recommendations may also be applied to watersheds with similar mercury pollution problems such as neighboring Putah Creek. In order to address these questions we will provide the BLM
with a matrix of remediation strategies that could address the mercury issues within the Cache Creek Basin, evaluate the benefits of different remediation strategies on mercury levels, present a policy analysis, and analyze the logistical concerns and issues, such as accessing remote sites that may be designated wilderness. In addition to our recommendations about effective remediation strategies, we will recommend a monitoring plan, and provide a timeframe of mercury concentrations in the future and when they may meet the TMDL requirements.

**PROJECT OBJECTIVES**

The Environmental Protection Agency (EPA) and the Central Valley Regional Water Quality Control Board have established maximum mercury concentration levels for both water and biota, which are currently being exceeded within the Cache Creek Basin. The Bureau of Land Management, which manages approximately 300 square miles of the Cache Creek Basin, has significant interest in controlling mercury diffusion from abandoned mine lands and the mercury that has accumulated in the sediments downstream of these lands. While the BLM and other landowners have initiated significant cleanup efforts on these abandoned mine lands, many questions remain:

- What strategic actions should the BLM adopt on its public lands to control mercury contamination originating from upstream mine sources outside BLM lands when the likelihood of near-term mine cleanups on private lands is low?

- At what rates will mercury loads in the Basin decline over time, under different cleanup scenarios at both mine sites and sites with downstream contamination?

- How will the BLM know when it has successfully attained levels below TMDL limits set for mercury and methylmercury by the CVRWQCB?

- What techniques should the BLM employ to remove or mitigate mercury contamination from the Harley Gulch area inside the Cache Creek Wilderness, situated downstream from the Abbott-Turkey Run mine complex, the largest single source of mercury in the Basin?

- Are the high levels of sulfur and other metals contributing to the mercury problem, and if so, how might these be reduced?

- From a policy perspective: What improvements to regulatory and agency policies and working relations among multiple agencies would facilitate efficient management of mercury in the Basin? In what ways can the BLM be instrumental in achieving these improvements? What are the legal constraints for the various management actions as outlined by EPA, CVRWQCB, or general California law?

- How to deal with management constraints for type of equipment and disturbance in wild areas?

The objective of this project is to find the most effective strategies to answer the above questions and successfully reduce mercury levels below the TMDL requirements in the Cache Creek Basin. The BLM
has emphasized the value of recommendations of new and innovative strategies in controlling mercury; as an academically multidisciplinary team, we will incorporate ecology, geology, chemistry, hydrology, economics, and policy in our solution.

PROJECT SIGNIFICANCE

Mercury pollution is one of the most challenging environmental problems to solve, primarily because extremely low concentrations are considered toxic. While all forms of mercury are toxic, it is organic mercury, or methylmercury, that bioaccumulates in organisms and becomes problematic for people and wildlife that consume fish exposed to water with elevated levels of mercury. Mercury has been shown to cause a number of developmental disorders in pregnant women and children; these at-risk segments of the population should restrict or avoid consumption of many types of fish. In several areas of the Cache Creek Basin, historic mining activities have led to high concentrations of mercury in both the water and fish. In addition, the Cache Creek Basin is a major contributor to elevated mercury concentrations in the Sacramento River and San Francisco Bay Delta, both of which contain active fisheries. Many people that consume fish from these regions are not aware of the mercury pollution problem and exceed recommended limits of contaminated fish. In addition to humans, mercury pollution can be harmful to wildlife, including several endangered species in the Basin. Proper cleanup of abandoned mine lands is a critical step in meeting TMDL requirements, and the CVRWQCB has tasked the BLM to assist in meeting these requirements.

BACKGROUND INFORMATION

Cache Creek

The Cache Creek Basin is located in northern California and occupies 2,978 km² (Suchanek et al., 2010) (Figure 1). The upper part of the watershed, upstream of Rumsey, is within the California Coast Ranges and the lower part of the watershed, downstream of Rumsey, is part of the Sacramento Valley. The landscape above Rumsey consists largely of low mountains containing forests of mostly oaks and conifers, shrub lands, grazing lands, and some farmland. Below Rumsey, the majority of the landscape is farmland. Elevations range from a low of 8 meters, at the confluence of Cache Creek and the Yolo Bypass, up to 1,815 meters, with a large majority being from 300 to 800 meters. Precipitation in the region averages 20-40 inches per year and falls primarily between the months of November to April.

Clear Lake, the source of the South Fork of Cache Creek, is the largest natural freshwater lake in California. It is fed by a number of smaller creeks, none of which are significant sources of mercury. Clear Lake contains a small dam built in 1914, which adds an additional 270,000 acre-feet of storage and helps regulate flow throughout the year (Lake County, 2009). In addition to providing Lake and Yolo Counties with drinking and irrigation water, the Cache Creek Basin attracts tourists for a variety of reasons. There are several noteworthy regional, state, and national fishing tournaments at Clear Lake. Visitors to Clear Lake’s Konocti Harbor Resort and Spa enjoy gambling and concerts held at their outdoor amphitheater. In addition, a resort and spa located at Wilbur Springs makes use of the local hot
springs. An increasing amount of wine grapes are grown in the region, with many wineries and tasting rooms under construction. Several state parks surround Clear Lake and provide excellent wildlife viewing and camping. During peak flow months, Cache Creek and the North Fork of Cache Creek are commonly used for kayaking and other river activities. Unfortunately, Clear Lake is significantly polluted with mercury from the Sulphur Bank Mine, which was declared a Superfund site in 1990 (Sulphur Bank Mercury Mine, 2010). Clear lake contains one of the three TMDLs in the Cache Creek Basin, and the EPA has recommended limits on fish consumption from the lake. In addition to Clear Lake, the Basin contains Indian Valley Reservoir on the North Fork of Cache Creek with a capacity of 300,000 acre-feet (CDEC, 2010), as well as the much smaller Davis Creek Reservoir.

Figure 1. Map of Cache Creek Basin
Mercury Sources

Sources of mercury to the Cache Creek Watershed include geothermal springs, erosion of naturally mercury-enriched soils, atmospheric deposition, sediment enriched with legacy mercury, as well as waste rock and tailings from historical mines. Unlike other regions of the country, atmospheric deposition of mercury in the Cache Creek Basin is relatively small compared to the contributions from other sources (Churchill and Clinkenbeard, 2003). It is more likely that the region is a larger source of atmospheric mercury rather than a sink. Soils that contain naturally elevated levels of mercury are common in the region, especially in mining regions. Weathering of bedrock is enhanced by the hydrothermal processes in the area, contributing to elevated mercury concentrations (Suchanek et al., 2010). It is believed that the largest sources of mercury are from geothermal springs, mine materials and sediment in the banks and beds of the streams below mining areas (Figure 2).

The Cache Creek Basin is geologically complex with multiple faults, old volcanoes, and different types of soil and bedrock (Suchanek, 2010). The rock types include: quaternary deposits, volcanic rocks, Great Valley sequence, Coast Range ophiolite, and the Franciscan Complex. The high heat flow associated with volcanism deposited high concentrations of mercury, gold, and silver in the area. Even without human disturbance, concentrations of mercury in Cache Creek would be very high. It is estimated that 38-57% of the total mercury from Cache Creek is from natural sources, bringing into question how effective remediation efforts will be in meeting the TMDL requirements (Churchill & Clinkenbeard, 2003). Many hot and cold springs exist in the area, and contribute various amounts of mercury and other minerals, depending on their chemical makeup. Several of the hot springs near Wilbur Springs have very high concentrations of mercury and methylmercury. However, the hot spring that flows out of the Turkey Run mine has a very low concentration of mercury, but an extremely high concentration of sulfur. It contributes only 0.005-0.006 kg/yr of mercury, but 51,000-160,000 kg/yr of sulfur (Churchill & Clinkenbeard, 2003). These high levels of sulfur are important to consider because they have been implicated in increasing the methylation of mercury by sulfur reducing bacteria. In addition, unknown springs may exist, especially in creek beds, making it difficult to quantify mercury contribution from the springs. Springs often form a black precipitate that contains a variety of metals including mercury that will accumulate during the dry season. The first large rain event of the wet season flushes this precipitate into the creek. Fortunately, the springs and the creeks in the area have a pH that is moderately basic and acid mine drainage is not a problem (Churchill & Clinkenbeard, 2003).
Mercury mining in the region began in the mid nineteenth century in order to assist gold extraction from ore in the booming gold mining industry located in the foothills of the Sierra Nevada (Domagalski et al., 2004). In the Sulphur Creek Mining District, Abbott-Turkey Run was by far the biggest mine. Between one and two miles of underground tunnels exist there, and at least 1.8 million kg of mercury were mined. The rest of the mines in the area are small in comparison, with a cumulative 200,000 kg of mercury mined, but their contributions to mercury pollution are also significant because of the high erosion rates at these locations. In the Sulphur Creek Mining District, 220,000 out of 267,000 tons of tailings are downhill of where the furnace used to be at the Abbott-Turkey Run mine, (Churchill & Clinkenbeard, 2003). Many of the mines had their ore processed at nearby mines, and as a consequence not every mine contains tailings. The last mercury mine closed in 1971, probably not coincidentally around the same time when many environmental regulations began. Before this time there was little understanding and appreciation of the toxicity of mercury at the mines and processing facilities. Therefore, waste rock and tailings that contain very high concentrations of mercury were left behind after those facilities closed. These tailings are often on steep slopes and are highly erodible. As the location of most of these mines is very close to tributaries of Cache Creek, rainfall and resulting erosion lead to much of the tailings ending up as sediment in creek beds, with some eventually washing into the Sacramento River and San Francisco Bay Delta. This sediment can remain in a creek bed for long periods of time, and may be resuspended in subsequent years, especially during high flows. Although some
remediation efforts, such as the removal of mining waste and erosion prevention measures, have taken place in the last couple of decades, a great deal of mercury is still eroding into the streams from the exposed rock of these old mines.

Multiple studies have been performed to better understand the magnitude of each of the different mercury sources in order to focus mitigation efforts. Results of these studies have varied depending upon the timeframe in which samples were collected and the manner in which the analysis was performed. However, there are key points of consensus within these studies. It is generally accepted that although high levels of mercury and methylmercury are found in the settling basin, the major source of both come from the watershed upstream of Rumsey (Figure 3). Also, there is general agreement that Harley Gulch and Sulphur Creek, which drain into Bear Creek, are key tributaries of concern. The Abbott-Turkey Run Mercury Mine Complex is a region of key concern for the BLM in their remediation efforts because the region contains the largest quantity of mine tailings and has contributed significant quantities of legacy mercury into the sediments of Harley Gulch. Harley Gulch contains one of the three TMDLs in the Cache Creek Basin and the BLM is partially responsible for returning mercury concentrations in the water to acceptable levels.

There are multiple other historical mines found in the Sulphur Creek Mining District. This, combined with geothermal springs and naturally mercury-enriched soil, creates high mercury concentrations in local streams. Sulphur Creek drains into Bear Creek, which contains the third mercury TMDL and is a major tributary of Cache Creek. According to the CVRWQCB’s report on Bear Creek, only 22% of the total mass of sediment in Bear Creek originates from the Sulphur Creek confluence, but contains 85% of the total mercury mass in Bear Creek (Central Valley Regional Water Quality Control Board, 2009b). From this study, it has been concluded that Sulphur Creek is the main contributor of mercury to Bear Creek. However, there is conflicting data as to whether Harley Gulch is a larger contributor of mercury to Cache Creek than Sulphur Creek. Studies that show Harley Gulch to be a smaller contributor, such as Domagalski, et al. 2002b, mostly looked at data from 2000 and 2001. Those years were quite dry and the overall assumption is that low flow rates during that timeframe may have led to an underestimation of mercury contributions from Harley Gulch (Regional Water Quality Control Board Central Valley Region, 2004). While much of the mercury exported from Sulphur Creek originates from hot springs, mercury originating from Harley Gulch is almost exclusively eroded from mine tailings, which may not become mobilized except during large storms (Domagalski et al., 2004b). Therefore, a usual source of mercury to Harley Gulch was not regularly contributing in these uncharacteristically dry years. Also, it is strongly believed that a major source of mercury within the entire Cache Creek basin is the resuspension of mercury from sediments in the creek beds (Regional Water Quality Control Board Central Valley Region, 2004). This sediment disturbance and transport only occurs with sufficient stream flows, so this would not occur as much during years with less rainfall. Since Harley Gulch typically has lower flows, it would be more affected by this change in precipitation.

Other major sources of mercury are Davis Creek, a tributary of Cache Creek, and Clear Lake. The Reed Mine contributes mercury into Davis Creek, but studies show that this is a much smaller source than Sulphur Creek or Harley Gulch (Domagalski et al., 2004b). Sulphur Bank Mercury mine has contributed a significant amount of mercury to Clear Lake, which has resulted in additional contributions to Cache
Creek. Remediation efforts by the EPA have lowered Clear Lake’s mercury contribution and it is now less of a concern than the other sites.

Figure 3. Mercury Sources in Cache Creek Watershed
Mercury Chemistry

Mercury exists primarily in three varieties: elemental mercury Hg(0); divalent salts Hg(II) which include HgCl₂, Hg(OH)₂, and HgS; and methylmercury (MeHg) (Schroeder and Munthe, 1998). In the Cache Creek Basin, the largest quantity of mercury is HgS, otherwise known as cinnabar (trigonal HgS) or metacinnabar (cubic HgS). Cinnabar ore, which is the mineral that miners sought, can contain concentrations of mercury as high as 15% (Pearcy and Peterson, 1990). Hg(II) itself is not a concern because it does not bioaccumulate, but it can be reduced to MeHg by biotic and abiotic processes (Marvin-DiPasquale and Agee, 2002). The primary method of this reduction is by sulfur reducing bacteria that live in the top layers of sediment in wetlands. The methylation of Hg(II) is particularly rapid in anaerobic conditions. Methylation can also occur abiotically when fulvic and humic acids are available, but, absent of acidic conditions, biotic processes will dominate (Nagase et al., 1982). Methylation is counterbalanced by biotic and abiotic processes that demethylate MeHg (Hudson et al., 1994). These processes tend to dominate in aerobic conditions that receive direct sunlight. Demethylation converts MeHg to Hg(0), which has a very high Henry’s constant, and will quickly volatilize into the atmosphere.

Although there are processes that convert Hg between the three different varieties, there are no known equilibrium constants between the concentrations of the three varieties (Chen, 2003). Therefore, a high concentration of Hg(0) or Hg(II) does not necessarily imply a high concentration of MeHg, although methylation and demethylation rates are proportional to their concentration in the water and sediment and the other environmental conditions that exist, such as dissolved oxygen concentration and pH (Xun et al., 1987). Methylmercury is the only variety of mercury that bioaccumulates and is found in fish; therefore, this is the variety that must be limited to reduce human mercury consumption. MeHg concentrations in fish are a function of MeHg concentration in the water, trophic level of the fish, and age of the fish (Back et al., 2002).

All three varieties of mercury have a very high soil adsorption coefficient (Kₐ), which means mercury has a high affinity for adsorbing onto both suspended and settled sediments (Lyon et al., 1997). This is important because it implies that if the flux of total suspended sediments from a mining region is limited, the flux of mercury will also be limited. As suspended sediment settles out of water, like it does in the Cache Creek Settling Basin, it has a very high concentrations of Hg(II) and is prone to methylation during the anaerobic conditions prevalent in the dry season.

Ecological Effects of Mercury Contamination

Cache Creek Basin provides a number of beneficial uses from recreation to habitat for wildlife (Cooke and Morris, 2005; Cooke et al. 2004). There have been over 154 species of birds observed, including peregrine falcons and the endangered southern bald eagle (Schwarzbach et al., 2001). A number of game and non-game fish including channel catfish, brown trout, smallmouth bass, Sacramento pikeminnow, Sacramento sucker, and California roach also inhabit the watershed (Cooke and Morris, 2005). While the watershed provides valuable habitat for a number of wildlife species, high mercury levels threaten these uses. Increased mercury levels can lead to a number of adverse effects on wildlife and human health. In
the Cache Creek Basin it is particularly important to manage mercury at a safe level to avoid transport of mercury into the San Francisco Bay and Delta as well as to protect humans and wildlife that eat fish from the area (Cooke and Morris, 2005).

One reason mercury is concerning is due to its ability to bioaccumulate within organisms and to be magnified as it transfers to higher trophic levels within food webs. According to Domagalski et al. (2004b), “the bioaccumulation of mercury in fish is one of the most widely recognized environmental problems of the current era.” Organisms can accumulate mercury from multiple sources including water, sediment, and other organisms. However, “before mercury can bioaccumulate, the inorganic form must be converted to the organic (methylmercury, CH$_3$Hg$^+$) form” (Domagalski et al., 2004b).

Methylmercury is the most common form of organic mercury in natural systems (Nichols et al, 1999). In its methylated form, mercury becomes more bioavailable because it is more soluble in water than its inorganic form (Alpers et al., 2008). Methylmercury is also able to cross cell membranes allowing it to be more easily accumulated within organisms (Alpers et al., 2008). Alpers et al. (2008) explains that methylmercury has the ability to form strong bonds with biological proteins making it easier for organisms to retain and transfer the mercury to other organisms. Thus, concentrations become magnified as they move up trophic levels to predatory organisms like piscivorous fish and birds (Domagalski et al., 2004b). In the Cache Creek Basin, correlations have been found between the concentrations of methylmercury in lower trophic level organisms and adult sport fish (Alpers et al., 2008). Studies in the Bay-Delta Estuary have shown that bioaccumulation trends can also be linked to seasonal fluctuations of methylmercury (Alpers et al., 2008).

The primary target of methylmercury is the central nervous system (Nichols et al., 1999). As a result, methylmercury contamination causes a number of neurological effects. Wildlife including invertebrates, fish, birds, and mammals experience adverse effects when exposed to elevated levels of mercury. In the Cache Creek Basin and the San Francisco Bay-Delta, this is a concern because many studies have measured mercury concentrations in wildlife above recommended thresholds (Alpers et al., 2008; Domagalski et al., 2004b). As of 2005 there had been no studies directly linking the adverse effects of mercury exposure to wildlife; however, it can be difficult to detect nonlethal effects of mercury in organisms like fish (Cooke and Morris, 2005). Therefore, elevated mercury levels are still a concern because piscivorous fish in the watershed are estimated to exceed safe levels for consumption by humans and wildlife (Cooke and Morris, 2005). Slotton et al. (2004) found that piscivorous fish in Bear Creek had levels of mercury mainly between 2 and 4 µg/g and detritivorous fish also showed elevated levels of mercury well above the 0.3 µg/g standard established by the TMDLs.

Fish are exposed either by consuming contaminated benthic macro-invertebrates or other contaminated fish. Lower trophic level fish can become contaminated by consuming invertebrates and detritus; higher level predatory fish are exposed when they consume other fish. Decreased reproductive success, altered behavior, and impaired developmental growth are among some of the effects that fish can experience from exposure to an increased level of mercury (Alpers et al., 2008).

Predatory birds and mammals are also at risk in the watershed when they consume fish with elevated levels of mercury. Both mammals and birds have been shown to experience “impaired neurological
development and learning behaviors” when exposed to mercury (Alpers et al., 2008). According to Cooke and Morris (2005), behavioral effects such as “impaired learning, reduced social behavior and impaired physical abilities have been observed in mice, otter, mink, and macaques exposed to methylmercury.” In the Cache Creek Basin, river otters may be at risk of contamination (Alpers et al., 2008). Of most concern are the peregrine falcon and the endangered southern bald eagle that inhabit the watershed. Nesting and wintering bald eagles have been observed preying on large forage fish that may have elevated levels of mercury, especially from November to March (BLM, 2004).

Amphibians are another group of organisms that can be negatively impacted by increased levels of mercury in aquatic environments. One sensitive species found in the Cache Creek Basin is the Foothill Yellow Legged Frog (BLM, 2004). These organisms are affected because they prey on invertebrates and persist in areas where even fish may not find the habitat suitable (Hothem, 2008). As a result, they may experience effects like reduced survival, growth inhibition, behavioral modification, impaired reproduction, and malformations of larvae (Hothem, 2008).

Humans are primarily exposed to methylmercury by eating contaminated fish (Alpers et al., 2008; EPA, 2001). Cache Creek is fished year round mainly for sport fish such as Channel Catfish and Smallmouth Bass (Alpers et al., 2008; Cooke and Morris, 2005). Much of the knowledge about mercury toxicity in humans comes from poisoning events that occurred in Minamata, Japan from contaminated fish as well as in Iraq, Guatemala, and Pakistan from grain contaminated with mercury (Alpers et al., 2008). These events showed how neurotoxicity is the biggest concern for humans and that developing organisms and children are most susceptible (Alpers et al., 2008; EPA, 2001). Some of the signs and symptoms from methylmercury poisoning are lowered immune system response, decreased reproduction, hearing, vision, and speech impairments, coma, and death (Batten and Scow, 2003). However, these effects were observed from extreme events and are not likely to occur with lower levels of mercury exposure that might occur from eating contaminated fish (Alpers et al., 2008).

**Regulatory Framework and Economic Considerations**

*Regulations*

The BLM has various regulations they must follow to clean up their land in the Cache Creek Basin, but they must also follow regulations and implementations stated in the Federal Land Protection Management Act (FLPMA). Under FLPMA, the BLM’s responsibility is to "provide the public the opportunity to use and appreciate significant cultural and natural resources while protecting and conserving them” (BLM, 2008). With FLPMA in mind, BLM’s management goal is to "maintain the health of the land and, to the best of its ability, to restore or replace resources that are harmed by pollution” (BLM 2008). This management goal is important for BLM and their cleanup efforts in the Cache Creek Basin.

The U.S. Clean Water Act (CWA) requires states to identify beneficial uses of water bodies in the state, any waters that are not meeting water quality standards, and remediation and clean up measures to meet water quality standards (CVRWQCB, 2009). To accomplish this goal, California’s water code created the State Water Resources Control Board and nine regional offices underneath Division 7 (also
known as the Porter-Cologne Water Quality Control Act) to ensure compliance and implementation. The Cache Creek Basin is inside the jurisdiction of the Central Valley Regional Water Quality Control Board ("Control Board").

To accomplish the regulations that were given to the Control Board, the Control Board created the Water Quality Control Plan ("Basin Plan") for the Sacramento River and San Joaquin River basins. The Basin Plan includes beneficial uses, water quality objectives, implementation, as well as surveillance and monitoring (CVRWQCB, 2009b). The Basin Plan also has more information about covering costs, individual discharges, and action recommendations (CVRWQCB, 2009b). With the significant amount of mercury in Cache Creek, the Cache Creek Basin has its own section in the Basin Plan titled the "Cache Creek Watershed Mercury Program" ("Program") (IV-33.12) (CVRWQCB 2009b). The Program states the amount of methylmercury that is allowed in the Cache Creek and its tributaries (Table 1) (CVRWQCB 2009b). In addition, the mines in Table 2 are sites required to have a 95 percent total mercury load reduction from their average annual load estimate (CVRWQCB, 2009b). The Program also outlines monitoring protocol, erosion control, road construction and maintenance, and miscellaneous other requirements (CVRWQCB, 2009b).

To comply with the Basin Plan, beneficial uses of the Cache Creek Basin were identified. The uses that were listed comprise of industrial process supply, contact and non-contact water recreation, irrigation, and others (CVRWQCB, 2009). As stated before, to maintain these uses, the state established Water Quality Objectives (WQOs) and implementation policies to achieve these WQOs. WQOs are numeric objectives like maximum contaminant levels (MCLs), TMDLs, odor, and color (CVRWQCB, 2009). Many tributaries in the Basin are not meeting water quality standards due to mercury coming from abandoned mines. In particular, mercury is affecting municipal and domestic water supply, recreation, and wildlife habitat (CVRWQCB, 2005b).

Table 1. Cache Creek Basin methylmercury allocation.

<table>
<thead>
<tr>
<th>Source</th>
<th>Existing Annual Load (g/yr)</th>
<th>Acceptable Annual Load (g/yr)</th>
<th>Allocation (% of existing load)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cache Creek (Clear Lake to North Fork confluence)</td>
<td>36.8</td>
<td>11</td>
<td>30%</td>
</tr>
<tr>
<td>North Fork Cache Creek</td>
<td>12.4</td>
<td>12.4</td>
<td>100%</td>
</tr>
<tr>
<td>Harley Gulch</td>
<td>1</td>
<td>0.04</td>
<td>4%</td>
</tr>
<tr>
<td>Davis Creek</td>
<td>1.3</td>
<td>0.7</td>
<td>50%</td>
</tr>
<tr>
<td>Bear Creek at Highway 20</td>
<td>21.1</td>
<td>3</td>
<td>15%</td>
</tr>
<tr>
<td>Within channel production and ungauged tributaries</td>
<td>49.5</td>
<td>32</td>
<td>65%</td>
</tr>
<tr>
<td>Cache Creek at Yolo</td>
<td>72.5</td>
<td>39</td>
<td>54%</td>
</tr>
<tr>
<td>Cache Creek Settling Basin Outflow</td>
<td>87</td>
<td>12</td>
<td>14%</td>
</tr>
</tbody>
</table>
Since BLM owns a large portion of the Cache Creek Basin, it is considered the responsible party for maintaining water quality and preventing ongoing discharge of pollutants. This ownership holds the BLM responsible for cleanup on its property regardless of whether or not they were responsible for the initial discharge of pollutants (CVRWQCB, 2009). This responsibility subjects BLM to clean up orders issued from the Control Board. Clean up orders are created when beneficial uses of a water body are being affected by polluted water and WQOs are not being met (CVRWQCB, 2009). As stated in the California Water Code and the Basin Plan, wastes must be cleaned up to background levels or, if this is not achievable, to a level that is the most technologically and economically feasible (CVRWQCB, 2009). Because the clean up order is an enforcement action required by a regulatory agency and can be considered a minor action to mitigate the release of hazardous waste, the order is exempt from the California Environmental Quality Act (CEQA) (CVRWQCB, 2009).

The orders require technical and monitoring reports to be created to show remediation plans and give a timeline for when these reports need to be completed (CVRWQCB, 2009). Some examples of reports that are required in the clean up order are a Mining Waste Characterization Report, Mining Waste Characterization Work Plan, Surface and Ground Water Monitoring Plan, and a Site Remediation Work Plan (CVRWQCB, 2009). Clean up of the site must continue until the Executive Officer determines the site has had sufficient contaminant reductions to fully comply with the order (CVRWQCB, 2009). The BLM has received clean up orders for Clyde Mine, Rathburn-Petray Mine, and Elgin Mine. The Clyde Mine and Elgin Mine orders were issued in August 2009 and the Rathburn-Petray Mine order was issued in December 2005.

Other regulations that BLM must contend with are the Endangered Species Act (ESA) and Federal Antidegradation Policy. The Cache Creek Basin is home to a large group of endangered Southern Bald Eagles, Peregrine Falcons, and Yellow-Billed Cuckoos that must be taken into consideration when implementing cleanup efforts (CVRWQCB, 2005; EPA, 2010). The Federal Antidegradation Policy is a water quality standard program that is used in determining actions for different tiered water bodies (CVRWQCB, 2005; EPA, 2009). Though these regulations are important for the BLM and mercury cleanup, they will not be discussed in this proposal.

Table 2. Cache Creek Basin inactive mines that require 95 percent total mercury load reduction

<table>
<thead>
<tr>
<th>Mine</th>
<th>Average Annual Load Estimate (kg Hg/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abbott and Turkey Run Mines</td>
<td>7.0</td>
</tr>
<tr>
<td>Rathburn and Rathburn-Petray Mines</td>
<td>20.0</td>
</tr>
<tr>
<td>Petray North and South Mines</td>
<td>5.0</td>
</tr>
<tr>
<td>Wide Awake Mine</td>
<td>0.8</td>
</tr>
<tr>
<td>Central, Cherry Hill, Empire, Manzanita, and West End Mines</td>
<td>5.0</td>
</tr>
<tr>
<td>Elgin Mine</td>
<td>3.0</td>
</tr>
<tr>
<td>Clyde Mine</td>
<td>0.4</td>
</tr>
</tbody>
</table>
The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) is a federal regulation that allows for cleanup of hazardous waste, but is implemented by the EPA rather than the BLM (EPA, 2010b). Within the Cache Creek Basin, only one mine has been authorized underneath CERCLA—Sulphur Bank Mercury Mine. It was proposed for the National Priorities List (NPL) in June of 1988 and was approved August 1990 (EPA 2010). The NPL under CERCLA is more of a process than a plan, but it creates a way for hazardous waste sites to be cleaned up (EPA, 2010b). It also holds previous or current owners responsible for cleanup costs, or if no previous or current owner is found, the government may sponsor the cleanup with money from the Superfund, which was created specifically to cover the costs of remediating hazardous waste sites under CERCLA (EPA, 2010b).

The Sulphur Bank Mercury Mine’s contaminated areas are groundwater, surface water, soil and sludges, and environmentally sensitive areas (EPA, 2010). Clean-up efforts started in 1992 and the most recent work was conducted in early 2008 (EPA, 2010). The EPA has removed soil, cut back the slope of mine waste to control erosion, created a surface water diversion, and removed mine waste from gravel roadways (EPA, 2010). Currently, BLM is urging the EPA to decide whether more sites should be considered for the NPL. If the EPA determined more sites do qualify for CERCLA, BLM would be allowed to seek contributions from previous owners to help cover the cost of cleanup. Mercury contamination remediation costs vary widely. Cleanup is not only metal-specific, but site specific as well (Wood, 2003). Factors that should be considered when estimating pollution remediation costs are listed in Table 3.

Table 3. Factors influencing remediation costs at mine sites (Wood, 2003)

<table>
<thead>
<tr>
<th>Category</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remediation goals</td>
<td>Level of cleanup required</td>
</tr>
<tr>
<td>Waste characterization sampling</td>
<td>Type and volume of material and waste, number and frequency of sampling events</td>
</tr>
<tr>
<td>Water quality</td>
<td>Degree of contamination: water and sediments</td>
</tr>
<tr>
<td>Site characteristics</td>
<td>Size of operation, site access, climate, geologic materials, elevation, topography</td>
</tr>
<tr>
<td>Liners</td>
<td>Soil, clay, amended soil, synthetic</td>
</tr>
<tr>
<td>Site hydrology</td>
<td>Precipitation, flow rate, water controls</td>
</tr>
<tr>
<td>Water treatment</td>
<td>Type of treatment, volume, management of treatment residuals, length of time required</td>
</tr>
</tbody>
</table>
Table 3 continued.

<table>
<thead>
<tr>
<th>Site operations</th>
<th>Effect on production; time to achieve remediation goals; total ore and waste rock tonnage; extent of site impacts; earthwork requirements, labor, imported material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulatory considerations</td>
<td>NPDES, CERCLA, dam safety requirements, local regulations</td>
</tr>
<tr>
<td>Water-quality monitoring</td>
<td>Number of analyses, laboratory analysis, size of area to be monitored, number of sampling stations, ground-water monitoring</td>
</tr>
<tr>
<td>Reclamation requirements</td>
<td>Area to be revegetated, type and amount of cover materials, feasibility and duration, post-reclamation land use</td>
</tr>
</tbody>
</table>

BLM’s responsibility, as stated before, is to restore resources; therefore, BLM has its own management system to achieve this. The Natural Resource Damage Assessment and Restoration Handbook (NRDAR) is a tool BLM may use to fulfill this responsibility (BLM, 2008). In many ways, NRDAR is similar to CERCLA in that it sets up a framework for BLM to assess and restore areas under its jurisdiction that have had physical damage from pollutant discharges, but it also allows the BLM to seek cleanup compensation from any potentially responsible party (PRP) (BLM, 2008). NRDAR also helps with normal site activities that are funded by BLM (BLM, 2008). While CERCLA is intended to minimize risks to public health and welfare and the environment, NRDAR is intended to help restore and replace natural resources (EPA, 2010). Currently, there is one NRDAR project being conducted at Harley Gulch.

Existing Remedial Technologies and Strategies to Improve Water and Sediment Quality

Organizations can employ several technologies and strategies to remediate mercury contamination in river basins caused by mine tailings. There are three major categories or types of remedial actions: (1) Containment, where the contaminant is restricted to a specified domain to prevent further spreading; (2) Removal, where the contaminant is transferred from an open to a controlled environment; (3) Treatment, where the contaminant is transformed into a nonhazardous substance (Pepper et al., 2006).

Containment Technologies

Containment can be accomplished by controlling the flow of fluid that carries the contaminant or directly immobilizing the contaminants (Pepper et al., 2006). There are three types of major containment technologies: physical barriers; hydraulic barriers; and in-situ encapsulation. These methods are applicable near abandoned mines within the Cache Creek Watershed.

Physical barriers

The purpose of a physical barrier is to control the flow of water to prevent the spread of contamination. Usually, the barrier is installed in front and down gradient of the contaminated zone (Pepper et al.,
The barrier consists of a vertically excavated trench that is filled with slurry (Figure 4). Most slurry walls are constructed of a soil, bentonite, and water mixture. Slurry walls are typically placed at depths up to 30 meters and are generally 0.6 to 1.2 meter thick (FRTR, 2002).

![Figure 4. Physical containment of a ground water contaminant plume with use of a slurry wall (FRTR, 2002)](image)

**Hydraulic barriers**

The hydraulic barrier is established by a drain system. The system is constructed by installing a perforated pipe horizontally in a trench dug in the subsurface and placed to allow maximum capture of the contaminated water. Water can then be collected and removed by using gravity or active pumping. The use of drain systems is generally limited to relatively small, shallow contaminated zones (Pepper et al, 2006).

**In-situ encapsulation**

In-situ encapsulation is accomplished by injecting a solution into the soil containing a compound that will encapsulate the contaminant. For example, cement or a polymer solution can be added, which converts the contaminated zone into a relatively impermeable mass encapsulating the contaminant. In addition, a major factor to consider for these techniques is the long-term durability of the solid matrix and the potential for leaching of contaminants from the matrix (Pepper et al, 2006). This strategy may also reduce release of the contaminant into the atmosphere (DTMC & SRWP, 2002).

**Erosion Control**

Erosion of mercury-laden soils from contaminated sites can be reduced by common erosion control practices such as drainage modifications, re-grading, re-vegetation, and slope stabilization (DTMC & SRWP, 2002).
Removal

Removing contaminants is the most fundamental method to remediate contaminated sites. Highly concentrated mercury-containing wastes such as those found at some mine sites are likely candidates for collection, shipment, and disposal at approved hazardous waste disposal sites (DTMC & SRWP, 2002). A very common, widely used method for removing contaminants is excavation of the porous media in which the contaminants reside. In addition to physical removal, an electrokinetic remediation method has recently been developed and used to remediate sites.

Excavation

Excavation has been used with a high success rate. There are, however, some disadvantages associated with excavation. First, excavation can expose site workers to hazardous compounds. Second, the contaminated media requires treatment and/or disposal, which can be expensive. Third, excavation is usually feasible only for relatively small, shallow areas. Excavation is most often used to remediate shallow, localized, highly contaminated source zones (Pepper et al, 2006).

Electrokinetic Remediation

The electrokinetic remediation process removes metals and organic contaminants from low permeability soil, mud, sludge, and marine dredging. The principle of electrokinetic remediation relies upon application of a low-intensity direct current through the soil between ceramic electrodes that are divided into a cathode array and an anode array. This mobilizes charged species, causing ions and water to move toward the electrodes (FRTR, 2002) (Figure 5). Metal ions including mercury move toward the cathode because they are positively charged.

![Electrokinetic System](image)

*Figure 5. Electrokinetic System (FRTR, 2002)*
Treatment (Biological Treatment)

Biological treatments are methods that allow in place cleanup of contaminated field sites by microorganism or plants. Major biological treatments for metals including mercury are phytoremediation and bioremediation.

Phytoremediation (Phytoextraction, Phytostabilization, and Rhizofiltration)

Phytoremediation is the treatment of environmental problems through the cultivation of vegetation. This method can be used to treat both organic and inorganic contaminants on site. There are three major types of phytoremediation relevant to remediating heavy metals; phytoextraction, phytostabilization and rhizofiltration.

Phytoextraction is primarily used for the treatment of contaminated soils. Contaminants are taken into and accumulated in plant tissues (Figure 6). Certain plants, called hyperaccumulators, can accumulate 100 times more metals than a common non-accumulating plant (Henry, 2000). Contaminants can be removed from the site by harvesting hyperaccumulators after the contaminants are accumulated.

Phytostabilization is the use of certain plant species to immobilize contaminants in the soil and groundwater through absorption and accumulation by roots, adsorption onto roots, or precipitation within the root zone of plants (Analya & Ramachandra, 2006).

Rhizofiltration is primarily used to remediate extracted groundwater, surface water, and wastewater with low contaminant concentrations (Henry, 2000) (Figure 7). Rhizofiltration is similar to phytoextraction, but the plants are used primarily to address contaminated ground water rather than soil (Analya & Ramachandra, 2006).

In order for phytoremediation to be feasible, the plants must (1) extract large concentrations of heavy metals into their roots, (2) translocate the heavy metals into the surface biomass, and (3) produce a large quantity of plant biomass. In addition, remediative plants must have mechanisms to detoxify and/or tolerate high metal concentrations accumulated in their shoots (Henry, 2000).

Advantages of phytoremediation are that it is relatively inexpensive and contaminants are actually removed from the site by harvesting the plants (Phytoextraction). However, phytoremediation use is limited to the sites in which the depth of contamination is within the root depth. In addition, it is relatively slow compared with other methods such as excavation. Wildlife may be exposed to the contaminants accumulated in the plant body if they eat plants before they are harvested. Furthermore, effects of introduction of nonnative species should be considered with phytoremediation.
Bioremediation technology uses microorganisms to reduce, eliminate, contain, or transform contaminants present in soils to benign products (Adeniji, 2004). There are two types of bioremediation: in-situ bioremediation is the in-place treatment of a contaminated site, and ex-situ bioremediation is the aboveground treatment as seen in sewage and drinking water treatment facilities. Although in-situ bioremediation is used primarily for organic contaminants (Pepper et al., 2006), there is emerging bioremediation technology to reduce using mercury resistant bacteria (MRB). MRB can transform toxic Hg\(^{2+}\) and methylmercury to non-toxic Hg\(^0\). Mercury can be contained and immobilized in the bodies of MRB, and mercury can be removed with bio-films. However, bioremediation utilizing MRB is still a developing technology and the bio-film method is mainly used for ex-situ treatment. Therefore, this method is not applicable to the Cache Creek Watershed.

Other treatment Technologies

There are many other treatment technologies for removing mercury from contaminated water such as coagulation and sedimentation, coagulation and filtration, granular activated carbon, lime softening, reverse osmosis and air stripping. However, these methods are mainly used for ex-situ treatment such as sewage and drinking water treatment facilities. Therefore, they are not applicable to the Cache Creek Basin.
**APPRAOCH**

*Additional Research*
- Collect various estimates of mercury concentrations and fluxes from different locations and sources
- Come to a consensus between disagreements in literature regarding differences in sources of mercury under varying environmental conditions
- Understand year to year variability in fluxes of mercury
- Identify gaps in knowledge in order to fill those gaps with field data collected during the summer
- Assess monitoring procedures to understand the successes of future remediation efforts

*Remediation Research*
- Research every possible option for mercury remediation
- Research remediation efforts already undertaken in the Cache Creek Basin
- Research remediation efforts at similar sites in order to understand their successes and learn from mistakes
- Understand which options apply to our five different categories of sources:
  - Waste rock, mine tailings, other exposed rock
  - Geothermal Springs
  - Legacy mercury in creek sediments
  - Upland wetlands
  - Lowland wetlands (Cache Creek Settling Basin, Yolo Bypass Wildlife Area)
- Research costs of remediation options
- Research effectiveness of different options
- Determine the most applicable options to each location by developing criteria to evaluate different options
- Understand how remediation efforts will decrease fluxes of mercury over time

*Data Modeling*
- Set up WARMF model with all necessary information
- Identify appropriate scale to model mining areas
- Incorporate the values from the consensus gathered from the research
- Calibrate the model to best match observed values
- Establish cleanup scenarios and incorporate estimated mercury reductions from the various cleanups

*Economics*
- Perform a cost benefit analysis for every remediation location given all applicable options
- Understand the amount of funding available and where it will come from
- Understand the health and environmental costs of pollution
Policy

- Understand BLM’s role in collaborating with other agencies and private landowners
- Make recommendations on how to deal with mercury problems upstream of BLM land
- Identify regulatory constraints
- Better understand the process and options that BLM undertakes to initiate site remediation

Mercury Modeling

As noted above in the Data Modeling section, we feel that the Watershed Analysis Risk Management Framework (WARMF) is the most appropriate computer model available to evaluate mercury pollution in the Cache Creek Basin. WARMF provides a comprehensive watershed modeling platform in order to model concentrations and fluxes of a large variety of pollutants, and contains all the biogeochemical interactions in order to correctly model all transformations (Chen et al., 2003). WARMF is an industry standard in modeling water bodies with TMDL requirements, and presents a framework for establishing remediation scenarios that provide results on how each of these scenarios will decrease pollutant concentrations over time in order to best meet the TMDL. The company that produces WARMF, the Electric Power Research Institute (EPRI) reviewed 118 papers on the current state of knowledge on the fate and transport of mercury within a watershed, and assembled that information to most accurately model each of the biogeochemical processes that mercury undergoes given the environmental conditions specific to that watershed. The model can then predict the current and future concentrations of mercury in each environmental compartment, including biota, under the various remediation scenarios.

In order to model the Cache Creek Basin, WARMF needs a variety of information including:

- A Digital Elevation Model (DEM)
- Land Use
- Soil Characteristics
- Point Source Data
- Stream Flow Data
- Meteorological Data
- Air and Rain Chemistry
- Wet and Dry Deposition Data

Much of this data is publically available from the USGS, EPA, or other government agencies, and the rest can be gathered from literature about the Sulphur Creek Mining District. WARMF divides a watershed into sub-watersheds, stream segments, and point sources, and allows uses to control the size of the sub-watersheds and stream segments in order to best model pollution runoff at an appropriate scale to the problem. This will allow us to increase the resolution of analysis surrounding mining areas in order to more accurately parameterize areas of concern.
MANAGEMENT PLAN

Group Structure & Responsibilities

Project Manager – Amibeth Sheridan
- Monitors progress to ensure deadlines are met
- Schedules weekly meetings and sets the agenda
- Promotes communication between team members
- Delegates tasks to other members if necessary

Project Secretary – Melissa Riley
- Takes minutes of meetings
- Helps project manager maintain schedule and deadlines

Financial Manager – Bethany Taylor
- Establishes and maintains group budget
- Tracks and records group expenses
- Point of contact for financial questions and issues

Data Manager – Nick Zigler
- Maintains and organizes the group’s online information
- Updates group e-mail
- Briefs the group on directory and file permissions
- Primary contact for modeling data

Web Manager and Final Review Manager– Kristiana Teige
- Designs and maintains the project’s website
- Ensures timely posting of information
- Updates the website as needed
- Reads final reports for continuity and clarity

Internship Coordinator – Toshiyuki Yamasaki
- Interacts with client to set-up summer internship
- Develops intern job description
- Coordinates internship logistics (e.g., housing, schedule, etc)

Expectations of Group Members and Faculty Advisor

Each group member is expected to come prepared to all meetings to ensure efficiency and productivity. The faculty advisor is expected to attend one scheduled meeting per week to ensure the project is on target. When the faculty advisor is in attendance, the members will focus on issues that concern the faculty advisor or are of interest to him. If need be, additional meetings will be set for the student members for administrative information that does not require the faculty advisor. In addition, students will be respectful of the faculty advisor’s schedule and allow ample time for responses to requests. It is expected that the faculty advisor will be able to provide assistance and constructive feedback to the group members throughout the project process. Each member will be professional, respectful, honest,
and patient with each member, the advisors, and the client. In addition, it is expected that each member will maintain internal deadlines for the project and do quality work.

**Conflict Resolution**

If any conflicts arise, the group members shall address it quickly and internally amongst themselves before seeking outside help. If there is a conflict with an advisor or client, the group shall seek help from Bren Faculty or Staff before approaching the advisor or client to ensure proper protocol and relationships are maintained.

**System to Ensure Deadlines are Met**

Deadlines will be identified and agreed upon by the group members. If a conflict on a deadline should arise, the project manager will make the final decision. In addition, the project manager will ensure that group members are aware of what needs to be accomplished. The project manager will also review upcoming deadlines and the progress of the team during each meeting to ensure the group maintains deadlines. If a group member cannot meet a deadline, the member will approach the entire group and the group will decide on how to assist and still meet the necessary deadline.

**DELIVERABLES**

Our deliverables mainly stem from the questions posed in the Objectives section above. We will provide our client with clear and specific information that addresses these questions. The following are more specific ways in which we plan to address them:

- Provide BLM with a matrix of remediation actions that could successfully address the continual mercury issue in Cache Creek. This would include a list of actions as well as the following information for each option: advantages; disadvantages; cost effectiveness; specific applications; and an outline of reasons why each solution would or would not work.

- Clear data depicting status quo and mercury decline under different scenarios. Either through a model (WARMF), provided that enough data is available to successfully model, or through more coarse calculations.

- Presentation of policy analysis, which would provide BLM with information about obstacles (e.g. legal constraints) as well as policies that may aid in their remediation efforts.

- Analysis of additional logistical concerns or issues, such as equipment restraints given the undeveloped nature of this area (e.g. areas inaccessible by road and restrictions on motorized vehicles in wilderness areas).

- Formal recommendation to BLM on the creation of a monitoring plan for remediation efforts.
# MILESTONES

## Spring Quarter 2010

<table>
<thead>
<tr>
<th>Task</th>
<th>Deadline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Submit final proposal to review committee</td>
<td>Tues, June 1</td>
</tr>
<tr>
<td>Proposal review meeting</td>
<td>Between June 1 – June 10</td>
</tr>
<tr>
<td>One-page summary of review meeting</td>
<td>Fri, June 11</td>
</tr>
<tr>
<td>GP weblink due to GP coordinator</td>
<td>Fri, June 11</td>
</tr>
<tr>
<td>Submit self/peer evaluation to faculty advisor and GP coordinator</td>
<td>Fri, June 11</td>
</tr>
</tbody>
</table>

## Summer 2010

<table>
<thead>
<tr>
<th>Task</th>
<th>Deadline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continue literature review</td>
<td>End of October</td>
</tr>
<tr>
<td>Data collection</td>
<td>End of October</td>
</tr>
</tbody>
</table>

## Fall Quarter 2010

<table>
<thead>
<tr>
<th>Task</th>
<th>Deadline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completed progress review</td>
<td>Fri, November 12</td>
</tr>
<tr>
<td>Complete models</td>
<td>Fri, November 12</td>
</tr>
<tr>
<td>Complete list of cleanup options/alternatives</td>
<td>Tues, November 30</td>
</tr>
<tr>
<td>Written progress report due to faculty advisor</td>
<td>Fri, December 3</td>
</tr>
<tr>
<td>Submit self/peer evaluation to faculty advisor and GP coordinator</td>
<td>Fri, December 3</td>
</tr>
</tbody>
</table>

## Winter Quarter 2011

<table>
<thead>
<tr>
<th>Task</th>
<th>Deadline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prepare defense presentation</td>
<td>Friday, January 14</td>
</tr>
<tr>
<td>Project defense</td>
<td>TBA – Weeks 5 &amp; 6</td>
</tr>
<tr>
<td>Draft of final report due to faculty advisor</td>
<td>Fri, February 18</td>
</tr>
<tr>
<td>Submit presentation program abstract to GP coordinator</td>
<td>Wed, March 9</td>
</tr>
<tr>
<td>Final report with all signatures due</td>
<td>Fri, March 18</td>
</tr>
<tr>
<td>Project brief due</td>
<td>Fri, March 18</td>
</tr>
<tr>
<td>Submit self/peer/faculty evaluations to GP coordinator</td>
<td>Fri, March 18</td>
</tr>
</tbody>
</table>

## Spring Quarter 2011

<table>
<thead>
<tr>
<th>Task</th>
<th>Deadline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take group photo with faculty advisor</td>
<td>1-2 weeks before GP presentation</td>
</tr>
<tr>
<td>Submit PowerPoint presentation to faculty advisor for review</td>
<td>1-2 weeks before GP presentation</td>
</tr>
<tr>
<td>Practice and videotape presentation (optional)</td>
<td>1-4 days before GP presentation</td>
</tr>
<tr>
<td>GP presentation</td>
<td>TBA</td>
</tr>
<tr>
<td>Turn in posters to GP coordinator</td>
<td>TBA</td>
</tr>
</tbody>
</table>
Budget

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phone Maintenance ($10 setup plus $1/month for 12 months)</td>
<td>$22</td>
</tr>
<tr>
<td>Phone Calls ($0.05/minute)</td>
<td>$21</td>
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<tr>
<td>Printing</td>
<td>$200</td>
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<td>Presentation Expenses</td>
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<td>Final Poster Production</td>
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<td>Final Project Prints</td>
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<td>Administrative Supplies</td>
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<tr>
<td>Miscellaneous</td>
<td>$657</td>
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<tr>
<td>TOTAL</td>
<td>$1500</td>
</tr>
</tbody>
</table>

Budget Justification

The Bren School of Environmental Science and Management will provide $1,300 to cover necessary costs, plus an additional $200 for printing costs. The group, through the Financial Manager, will address any adjustments to our budget. This budget will be updated to reflect the discussed changes within three business days.

- Phone: The telephone set-up fee is $10 with a maintenance fee of $1 per month. The cost of call is $0.05 per minute. Conference calls are needed to maintain communication with our client. Our budget allows for 7 hours of call time for 12 months (May 2010 through April 2011).
- Printing: Our initial $200 printing allotment will be used for routine printing of literature, legal documents, and document drafts. The professional printing of our final project poster and briefs are estimated to cost an additional $500.
- Presentation: We expect to spend $50 on our final presentation.
- Administrative supplies and miscellaneous: We anticipate spending up to $50 on administrative supplies, such as folders, binders, and other office supplies. The miscellaneous money incorporates our leftover funds that may be used for a conference, travel to Cache Creek, or any other needs that may arise.
CONTACT INFORMATION

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Other Information
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Project Website  http://fiesta.bren.ucsb.edu/~cachecreek
REFERENCES CITED


Cooke, J., & Morris, P. 2005. Amendments to the Water Quality Control Plan for the Sacramento River and San Joaquin River Basins for the Control of Mercury in Cache Creek, Bear Creek, Sulphur Creek, and Harley Gulch. Regional Water Quality Control Board Central Valley Region.


