

David Lawler<sup>1</sup>, Gregory J. Reller<sup>2</sup>

<sup>1</sup>US Department of the Interior Bureau of Land Management, [David\\_Lawler@ca.blm.gov](mailto:David_Lawler@ca.blm.gov), 2800 Cottage Way, Suite W-1834, Sacramento CA 95825-1886, (916) 978-4365

<sup>2</sup>Burleson Consulting, Inc., [gr@burlesonconsulting.com](mailto:gr@burlesonconsulting.com), 950 Glenn Drive, Folsom, California 95630, (916) 984-4651

(Technical Article IN: Hydrometallurgy 2008, 6<sup>th</sup> Intl Symposium Proceedings on Hydrometallurgy, 2008 Editors, Courtney A. Young, et. al, Society for Mining, Metallurgy and Exploration Inc. pp.170-172.

## ABSTRACT

Boston Mine is located in the Northern Mines Region of California and is part of the Red Dog Mining District located in Nevada County, to the east of Sacramento. Hydraulic Mines are located throughout the Northern Mines Region. Elemental mercury was widely used at placer mines to recover fine gold in ground sluices and sluice tunnels. Estimated annual loss of mercury to the environment during historical gold mining ranges from 10 to 30 percent resulting in potential releases of hundreds of pounds per site. Much of this elemental mercury remains within ground sluices, sluice tunnels, and stream sediment within the Mother Lode region. Typical features encountered at abandoned hydraulic mines include pits surrounded by high walls, ground sluices, pit lakes, drain tunnel inlets and drain tunnels. Free elemental mercury has been found in ground sluice, sluice tunnel, and stream sediments. Environmental impacts include mercury in surface water above water quality standards, bioaccumulation of mercury in the food chain, and direct exposure of recreational site visitors to free liquid mercury.

Regional sampling identified the drain tunnel outlet at the Boston Mine as a site of significant bioaccumulation in comparison to other placer mines that were sampled. Site specific investigations identified up to 45 grams of mercury per kilogram of sediment at the site. In addition, mercury in water from the drain tunnel outlet exceeded water quality standards. Characterization efforts included bulk sampling of sluice tunnel sediment to determine gold and mercury content, and a treatability study to determine if washed sediment would require special handling due to residual mercury content. Lead was identified as an additional chemical of concern as a result of the treatability study. Evaluation of removal alternatives identified removal of sluice tunnel sediments, gravity separation of elemental mercury, stabilization of washed sediment (if necessary), sealing of the sluice tunnel floor with concrete, and surface water diversion as the recommended removal action to address this site.

The removal action resulted in recovery of 1,162 grams of elemental mercury, 264 grams of amalgam, lead, and gold from site sediment. Washed sediment was suitable for burial on site without additional stabilization; heavy mineral concentrates were stabilized with cement prior to burial on site. The recovered mercury was recycled. Post removal monitoring is ongoing. This project highlights one way to manage mercury at abandoned hydraulic gold mines through use of existing, well understood technologies.

## INTRODUCTION

The Boston Mine is located in the Northern Mines Region of the Sierra Nevada Mountains, California, and is part of the Red Dog Placer Mining District, located in Nevada County, northeast of Sacramento. Hundreds of hydraulic gold mines are located throughout the Northern Mines Region. Elemental mercury was widely used at hydraulic mines to recover fine gold in ground sluices and sluice tunnels. Estimated annual loss of mercury to the environment during historical gold mining ranges from 10 to 30 percent. Estimates of the amount of mercury remaining in Northern Mines Region watersheds are in excess of 8.5 million pounds (United States Geological Survey [USGS] 2005). Much of this elemental mercury remains within ground sluices, sluice tunnels, and stream sediment within this region.

Environmental impacts related to the presence of mercury include mercury in surface water above water quality standards, bioaccumulation of mercury in the food chain, and direct exposure of recreational site visitors to free liquid mercury. Modern miners frequently encounter elemental mercury in streams and in sluice tunnels. Recent work has documented that the disturbances associated with recreational user activities within sluice tunnels directly increase the concentration of mercury in surface water (Tetra Tech 2004). Regional surveys have documented the accumulation of mercury in insects, frogs, and fish in the region (USGS 2004). Recognition of mercury above US Environmental Protection Agency and California levels for fish consumption has prompted the California Office of Environmental Health Hazard Assessment to produce sport fish consumption advisories for the region. A region that depends on sport fishery related tourism as part of its economic base.

## Hydraulic Mine Features

Typical features encountered at abandoned hydraulic mines include pits surrounded by high walls, the pit floor containing ground sluices, pit lakes or ponds, wetlands, sluice tunnel inlet shafts and sluice tunnels. Pit ponds and wetlands are known as potential mercury methylation sites, as are sluice tunnel sediments. The ground sluices were used to recover gold and to direct the flow of water and sediment into sluice tunnel inlet shafts. The sluice tunnels were driven under the placer deposits and represent the primary site of gold recovery at large hydraulic mines. These

tunnels provided a gravity drain, to remove water and sediment as the deposit was washed away during hydraulic mining. Sluice tunnels were lined with extensive sluiceboxes and elemental mercury was poured into the sluice riffles. The mercury amalgamated with fine gold, increasing gold recovery. Free elemental mercury is found in ground sluices, sluice tunnels, and stream sediments.

#### BOSTON MINE.

Regional sampling identified the sluice tunnel outlet at the Boston Mine as a site of significant mercury bioaccumulation in comparison to other placer mines that were sampled. Site specific investigations identified up to 45 grams of mercury per kilogram of sediment at the site (USGS 2004). In addition, mercury in water from the drain tunnel outlet exceeded water quality standards. Characterization efforts included mapping the site, bulk sampling of sluice tunnel sediment to determine gold and mercury content, and a treatability study to determine if washed sediment would require special handling due to residual mercury content. Lead was identified as an additional chemical of concern as a result of the treatability study.

A Removal Site Investigation (RSI) was performed to organize information from the site and document the need for a removal action (Tetra Tech 2004). The RSI considered the available data from analysis of water, sediment and biota samples; site features, and pathways for exposure of human and environmental receptors. The RSI also identified complete exposure pathways for humans through drinking water and direct contact. In addition, the biota at the sluice tunnel outlet contained the second highest mercury concentrations in the Bear and Yuba river watersheds (highest frog concentrations) (USGS 2004).

The RSI mapping identified surface water pathways through the site and located historical mining features. Surface water accumulates in the approximately 40-acre South Pit area. Most of the surface water drains northward into a system of three ponds or wetlands. Prior to remediation, the lowermost pond discharged to a historic ground sluice that flowed directly to the partially plugged sluice tunnel inlet shaft. During the winter season, surface waters then overflowed the inlet area and discharged overland through two remnants of ground sluices to the South Fork of Greenhorn Creek. A minor amount of runoff flows east into the Darling Creek tributary of the South Fork Greenhorn Creek. The sluice tunnel extends from the inlet shaft area approximately 250 feet northerly to the sluice tunnel outlet. The sluice tunnel outlet is located on a vertical rock face, approximately 22 feet above a plunge pool. Water discharged from the sluice tunnel outlet drops into the plunge pool and then flows overland into the South Fork of Greenhorn Creek.

From the outlet, the sluice tunnel is open for a distance of 220 feet, where a concrete bulkhead is encountered. The bulkhead was designed with a discharge pipe to allow drainage of water. The sluice tunnel contained sediment that averaged two feet in depth. Elemental mercury was contained in the sluice tunnel sediment and the plunge pool sediment. Site cleanup was necessary, based on risks to human health and the environment, due to the accessibility of elemental mercury in sluice tunnel and plunge pool sediments at the site.

Cleanup methods (referred to as removal alternatives) were evaluated in an Engineering Evaluation and Cost Analysis (EECA). The engineering evaluation included the following alternatives: No action, on site burial of untreated sediment in a mine waste repository, off-site treatment and disposal of sediment, and physical separation of mercury on site. These alternatives were evaluated using the criteria of effectiveness, implementability, and cost. Prior to final selection of the Removal Action, a treatability study was performed. A treatability study was necessary to determine whether physical separation would succeed, and if residual sediment would require special handling or be suitable for use as fill at the site.

#### TREATABILITY STUDY

The treatability study consisted of washing one ton of sluice tunnel sediment through a portable screening plant, and into a centrifugal bowl. Water, washed sediment, and mineral concentrate. Samples were collected to document treatability study results. Analytical results indicated that washed sediment did not contain elevated mercury and would be suitable for use as fill on site. However, the mineral concentrates would require stabilization prior to onsite disposal. Water samples collected during the treatability study indicated that wash water would require treatment prior to discharge into the South Fork of Greenhorn Creek, but that no treatment would be necessary if the water could be retained on site.

The treatability study results supported selection of the preferred removal alternative, which included removal of sluice tunnel sediments, gravity separation of elemental mercury, stabilization of washed sediment (if necessary), sealing of the sluice tunnel floor with concrete, and surface water diversion as the recommended removal action to address this site. Cleanup levels for washed sediment were established based on protection of ecological receptors with a concentration of 8 milligrams/kilogram (mg/kg) total mercury in washed sediment. The cleanup level for protection of water quality was based on a concentration of 10 times the local background concentration (0.203) micrograms/liter (ug/L) detected in the South Fork of Greenhorn Creek. Thus, the established cleanup level was 2.03 micrograms/liter

(ug/L) mercury. The 10-fold multiplier reflects the attenuation of mercury anticipated as water seeps through site soils. Both wash water and leachate concentrations were compared to the water quality concentration.

## REMOVAL ACTION

The Removal Action was completed during September and October 2005. Sediment was removed from the sluice tunnel using a slusher (miniature dragline-like underground mine apparatus). The slusher was mounted on a temporary platform immediately outside the sluice tunnel outlet. Removed sediment was dropped into the plunge pool area through a gap between the platform and tunnel floor. Sediment was picked up using a backhoe-loader and then transported to the processing plant. After the sediment was removed, the sluice tunnel floor was pressure washed to remove additional mercury. The cleaned floor was then sealed with concrete. Sediment from the plunge pool was excavated and the pool bottom was pressure washed and sealed with concrete. The concrete lining in the plunge pool was armored with cobbles and boulders collected from the site. Sediment blocking the sluice tunnel inlet shaft was excavated and then washed to remove elemental mercury. Samples collected from the bottom of the ground sluice did not contain significant amounts of elemental mercury, therefore ground sluice sediments were not excavated.

Excavated sediment was processed using a conventional placer gold recovery plant. The trommel (rotating cylindrical device) thoroughly washed the sediment. The oversize waste materials (cobbles and gravel) were discharged to the ground and the sand and fines flowed into the Clark Bowl (centrifugal heavy mineral concentration device). The Clark bowl separated the heavy mineral concentrates (mercury, lead, and gold) from less dense sand and fines, which then were discharged. The water and suspended sediment flowed to an infiltration basin where water percolated into the soil, and fines accumulated. Mercury and amalgam were separated from the heavy mineral concentrates in a spiral pan.

Samples of wash water collected from the infiltration basin documented that the average dissolved mercury concentration (1.9 ug/L) were below the 2.03 ug/L water quality protection goal. Samples of the settled fines contained 6.1 mg/kg total mercury; and samples of washed sediment contained from 0.51 mg/kg to 2.4 mg/kg total mercury; all below the 8 mg/kg cleanup level. The washed sediment was used to backfill the inlet shaft excavation and the adjoining ground sluice. Heavy mineral concentrates contained elemental mercury above the cleanup level and were stabilized by mixing with concrete. These stabilized concentrates were then encased in a minimum thickness of three inches of concrete and buried on site in the ground sluice.

The Removal Action resulted in recovery of 1,162 grams of elemental mercury, 264 grams of amalgam, and lead concentrate from the site sediment. 52 grams of placer gold were recovered from the 264 grams of amalgam. Washed sediment was suitable for burial on site without additional stabilization. Heavy mineral concentrates were stabilized with cement prior to burial on site. The recovered mercury was shipped to Bethlehem Apparatus Company for recycling and designated reuse for medical equipment. Post-remediation monitoring will occur for the next four years to document project success.

## CONCLUSION

This pilot project highlights a cost-effective method for elemental mercury cleanup in sluice tunnel sediments at abandoned hydraulic mines, using innovative modifications to conventional heavy mineral processing equipment and mining technologies.

## REFERENCES CITED:

- Tetra Tech. 2004. Removal Site Investigation Report for Boston Mine, Nevada County, California. March
- Tetra Tech. 2004. Results of Reconnaissance-level Mercury Sampling at the Pond Mine and Badger Hill Mine on September 8, 2004.
- United States Geological Survey (USGS). 2004. Geochemical characterization of water, sediment, and biota affected by mercury contamination and acidic drainage from historical gold mining, Greenhorn Creek, Nevada County, California, 1999-2001. Scientific Investigations Report 2004-5251.
- USGS. 2005. Mercury Contamination From Historical Gold Mining in California. Fact Sheet 2005-3014 version 1.1. Revised. October.