Providence Mine Brownfields Cleanup and Phytoremediation Pilot Study

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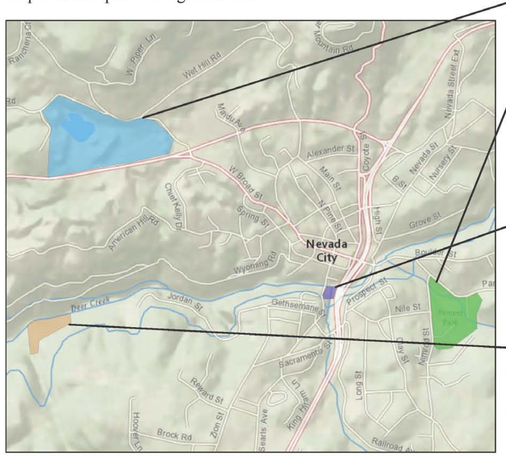
Abstract

The Providence Mine was one of the largest and most productive mines in the Nevada City Mining District, producing up to $20 Million in gold and silver between the 1850s and 1920s. The abandoned mine site is located on City owned property along Deer Creek near downtown Nevada City. Mine waste impacted by lead, arsenic, mercury and cadmium has been eroding into Deer Creek for over 150 years. Ongoing assessment and cleanup of the mine has been accomplished through collaboration between the City of Nevada City and Sierra Streams Institute (SSI) with grant funding from US EPA, The Sierra Nevada Conservancy (SNC) and the Rose Foundation. Assessment of the mine was performed as part of a 2006 EPA Brownfields Assessment Grant implemented by SSI under a subgrant agreement. Initial cleanup of the mine site was completed in 2014 with EPA Brownfields Cleanup Grant funding. Additional cleanup of an active landslide and unstable mine waste above Deer Creek is underway with SNC grant funding. A 2012-13 phytoremediation pilot study performed on the site by SSI with Rose Foundation grant funding showed successful uptake of arsenic, lead and cadmium into California native vegetation and successful germination from broadcast seeding. A follow up study is currently underway focusing on hydroseed and native plant erosion control and heavy metal phytostabilization.

Nevada City Brownfields Community Wide Assessment

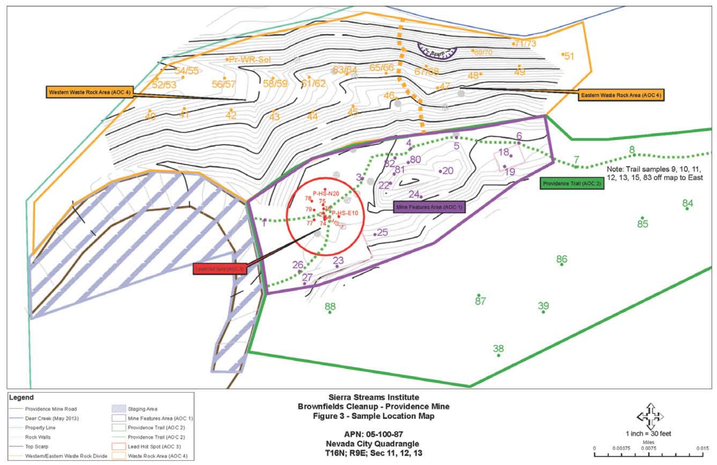
City owned properties were screened to identify abandoned mine sites. Four sites were sampled for heavy metal impacts from past mining activities:



- **Hirschmans Pond:** Hydraulic Mine Site, Elevated mercury in pond sediment, was generally below human health screening levels but may be linked to mercury in fish tissue.
- **Pioneer Park:** Elevated arsenic found in lower field soil at 20 to 116 mg/kg. City imported mine waste to fill wetlands in 1950s. Ineligible for EPA Brownfield cleanup grant.
- **Stiles Mill Site:** Public open space. Elevated lead (79 to 300 mg/kg) and arsenic (20 to 130 mg/kg) found in mine waste rock and mill tailings. EPA Brownfield cleanup grant awarded in 2010. Cleanup completed 2013.
- **Providence Mine Site:** Public Trail Open Space. Elevated lead (100 to 6700 mg/kg) arsenic (20 to 74 mg/kg) cadmium (up to 23 mg/kg) and mercury (up to 8 mg/kg) in mine waste and soil. Two EPA Brownfields cleanup grants awarded in 2010. Initial cleanup completed 2014.

Providence Mine Site Removal Action Workplan

Nevada City and SSI entered into a voluntary cleanup agreement with California EPA Department of Toxic Substances Control (DTSC) who provided regulatory oversight for the completion of site characterization, human health and ecological risk assessment and preparation of a Removal Action Workplan (RAW) for the Providence Mine site.

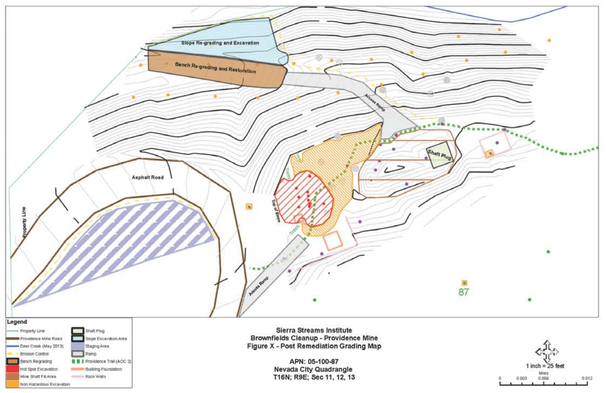


Site characterization data was evaluated to identify 4 Areas of concern (AOCs) at the site which were evaluated in a human health risk assessment to establish cleanup goals:

- AOC 1, Mine Features Area; Pb and As found in soil and mine waste. Goals of 280 mg/kg Pb and 21 mg/kg As.
- AOC 2, Lead Hot Spot; Pb in near surface soil exceeding Hazardous Waste levels (1000 mg/kg).
- AOC 3, Trail; soil on trail surface outside Mine Features Area did not exceed cleanup goals.
- AOC 4, Waste Rock Area: Steep mine waste eroding into Deer Creek. Engineered cleanup to control erosion.

Clean-Up Methods

Providence Mine in 1893. Deer Creek is in the right foreground; Champion Mine on the left. Brownfields "Mine Features Area" is within footprint of large building at upper right. "Waste Rock Area" is erosional remnant of steep mine waste pile at center of photo.



Post remediation grading map. 2014 Brownfields cleanup of shaft plug and backfill, Pb hot spot and nonhazardous soil excavation areas, regraded waste rock slope, and erosion control features. Steep slope in upper right will be addressed during 2015 Phase II Remediation project funded by the Sierra Nevada Conservancy.

Inclined Shaft Plug and Backfill

The collapsed inclined shaft of Providence Mine was excavated to remove debris and loose soil. A concrete plug was poured over the shaft. The depression was backfilled with non hazardous mine waste from site excavations, compacted, and covered with clean soil and wood chips.

Hotspot Excavation and Backfill

Soil exceeding hazardous waste levels for Pb (>1000 mg/kg) was excavated, stockpiled, characterized for disposal and hauled to a Class 1 landfill. The excavation was backfilled with clean soil and covered with wood chips.

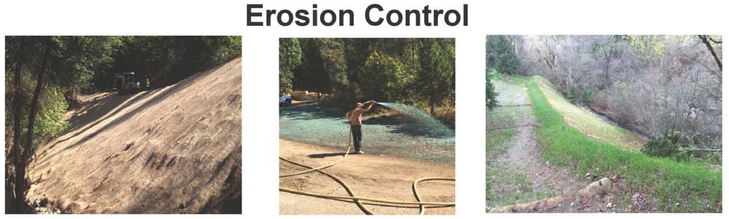
Mine Features Area Excavation and Backfill

Soil in the Mine Features Area exceeding cleanup goals (280 mg/kg Pb and 21 mg/kg As) was excavated and placed as backfill in the shaft depression. Confirmation soil sampling and analysis was performed. Excavations were backfilled with clean soil and wood chips.

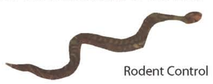
Slope Regrading

Steep mine waste slopes in the Waste Rock Area were regraded to lower slope angles to reduce erosion into Deer Creek. Slopes were reduced from approximately 1:1 Horizontal to Vertical (H:V) to 1.5:1 H/V. Excavated mine waste was placed as backfill in the shaft depression.

Erosion Control

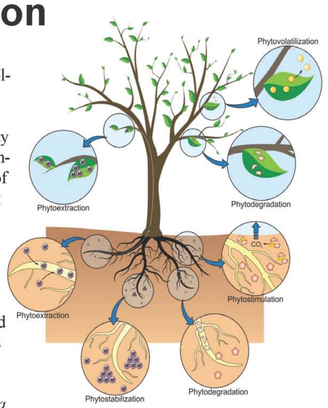


Coir Fiber Matting was installed on regraded slopes. Contained plants and hydroseed composed of California native grasses and wildflowers was applied to the coir matting, staging area and other disturbed areas of the site.

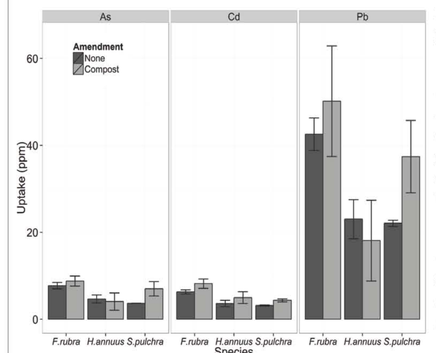


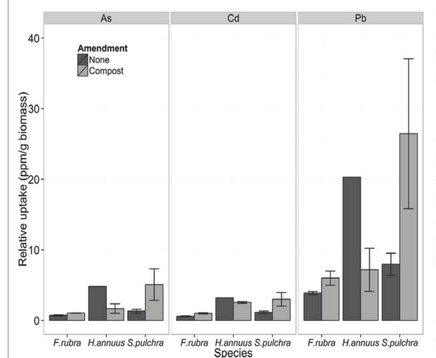
Phytoremediation

Phytoremediation is the use of green plants to extract or otherwise mitigate pollutant contamination. At Providence Mine and Stiles Mill, we tested phytoextraction (uptake of contaminants) capacity and metal tolerance as well as overall candidacy of native plants for revegetation of mine wastes. Replicated field plots using various amendments were used in a preliminary study to examine germination, survival, and uptake of select native species shown in previous lab studies to be classified as hyperaccumulators of target metals. A factorial potted-plant controlled experiment was then performed to assess germination, biomass production, and uptake by the top three candidates: *Festuca rubra*, *Helianthus annuus*, and *Stypa pulchra*.



Results





(Top) Measured uptake of Pb, As, and Cd in F. rubra, H. annuus, and S. pulchra in controlled potted plant experiment. (Bottom) Uptake of all three metals relative to biomass (g)

- *F. rubra* and *H. annuus* extracted significantly greater amounts of all three metals than other field trial plants (ANOVA $p<0.05$).
- Mycorhizal innoculation decreased extraction ($p<0.05$), while rock phosphate and compost treatment did not affect extraction.
- Compost was chosen for more comparison in potted study due to increased growth
- Potted plants in homogenized soils extracted >400% concentrations of field plants.
- *F. rubra* showed significantly greater uptake of Pb and Cd than either *S. pulchra* or *H. annuus* ($p<0.05$, Figure 2a) and produced significantly more biomass.
- *S. pulchra* showed significantly greater relative uptake (tissue metal concentration / total biomass production) than either *H. annuus* or *F. rubra* ($p<0.05$).

Conclusions

- Cleanup has significantly reduced potential exposure of humans and the environment to toxic metals.
- Additional mine waste remediation and slope stabilization, funded by the Sierra Nevada Conservancy, will further reduce the erosion of mine waste into Deer Creek.
- Phytormediation results were the first to demonstrate direct uptake of target metals into Purple Needlegrass, the CA state grass, and have directly influenced re-vegetation plans by augmenting planned plant pallettes. Results also prove feasibility of phytoremediation applications.
- Additional phytoremediation research is on-going, with current studies in progress examining local adaptation to metal contamination in willows to better inform mine waste re-vegetation.
- These projects provide a model for collaboration between municipalities, science based non profits and various funding agencies to cost effectively clean up abandoned mine sites on public property using novel methods.