Mining-influenced water treatment technology demonstration program – lessons learned from two EPA superfund sites

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Abstract

In 2019, EPA's Office of Superfund Remediation and Technology Innovation (OSRTI) initiated a mining site treatment technology field demonstration program for mining-influenced water (MIW). The program's primary goal is to identify and demonstrate promising technologies that improve, complement or serve as a viable alternative to conventional technologies for MIW at Superfund National Priorities List hardrock abandoned mine land and mineral processing sites. Candidate sites are selected to participate in one-to-three-year field demonstrations. This paper describes the innovative technologies and lessons learned from two of these sites: the Captain Jack Mill (CJM) Superfund site in Colorado and the Elizabeth Mine Superfund site in Vermont.

Keywords: Hardrock abandoned mine land, passive treatment, metals, remediation, acid mine drainage

Introduction

CJM Superfund Site

The CJM Superfund site is a former gold and silver mine located in the headwaters of Left Hand Creek, in Boulder County, Colorado, USA. The primary source of metals contamination to Left Hand Creek is the Big Five adit at the CJM Superfund site (fig. 1). The site is in a high topographic relief area with limited seasonal access and has limited flat space for sludge disposal or for retention times needed with passive treatment. As part of the original remedy design for the site, crushed limestone and a flow-control bulkhead were installed within the adit in November 2017 (EPA 2022). Closing outlet valves on the flow-control bulkhead was intended to inundate the mine workings, minimizing the oxidation reactions that generate acidic drainage. Prior to any treatment efforts, discharge from the adit was up to ≈ 200 L/s (≤ 50 gpm) of acidic water (as low as pH 3.4) with iron concentrations above 10 mg/L and other contaminants of concern in the tunnel water being cadmium, copper, and manganese (U.S. EPA 2008).

The Record of Decision noted the selected remedy was to be an innovative treatment technology and contemplated an option of adding organic carbon to the mine pool to create an in-tunnel sulfate reducing bioreactor with a goal to reduce metals and acidity loading to Left Hand Creek (EPA 2022). As the initial crushed limestone did not provide the treatment expected or necessary, the treatment was revised to include amendments to the mine pool. The initial in-tunnel treatment also included recirculation of mine pool water and amendment with alkalinity and organic carbon sources to a point ≈ 274 m or 900 ft in-bye the bulkhead. The CJM site was monitored through OSRTI's demonstration program to understand the mechanism and optimal performance for the in-tunnel treatment and measure the effectiveness in terms of reduced metals concentrations in the discharge relative to water quality standards.

Elizabeth Mine Superfund Site

The Elizabeth Mine Superfund site is in the towns of Strafford and Thetford in east-central Vermont, USA, on the eastern flanks of Copperas Hill. Active operations at the mine were conducted from the early 1800s until its closure in 1958 (EPA 2019). The ore from the mine was initially valued for its iron content and later for its copper content, from which copperas (iron sulfate) was produced. Mine waste materials left behind at the site contain sulfide minerals (e.g. pyrrhotite), which generate acid mine drainage. To treat discharge from a large tailings pile (Tailings Pile 1) having ≈ 363 kg/d iron, an active lime treatment, using a Rotating Cylinder Treatment System (RCTS™), was installed in 2008 and operated until 2018 (Butler et al. 2020). The active treatment was decommissioned in 2018 after source control measures reduced iron loads from the tailings pile, which provided an opportunity for EPA to transition to a less energy intensive and lower cost passive treatment system (PTS). PTSs at abandoned mine sites use low-maintenance processes with minimum chemical or energy input to adjust the pH of influent and encourage oxidation or reduction to assist in precipitating metal contaminants (Skousen et al. 2016). At this site, iron is the predominant contaminant targeted for treatment, with other metals typical at hardrock mining sites (e.g. arsenic, cadmium, copper, zinc) being at concentrations near to or below their detection limits. To understand climate influences and long-term performance of individual components within passive treatment trains, the Elizabeth Mine site is being monitored through OSRTI's demonstration program.

Methods

CJM Superfund Site

In the initial design concept, the flow control bulkhead would create ≈ 274 m (900 ft) of impounded water to operate as in-tunnel anaerobic sulfate-reducing biochemical reactor for treating pH, cadmium, copper, zinc, and other metals. Two external ponds

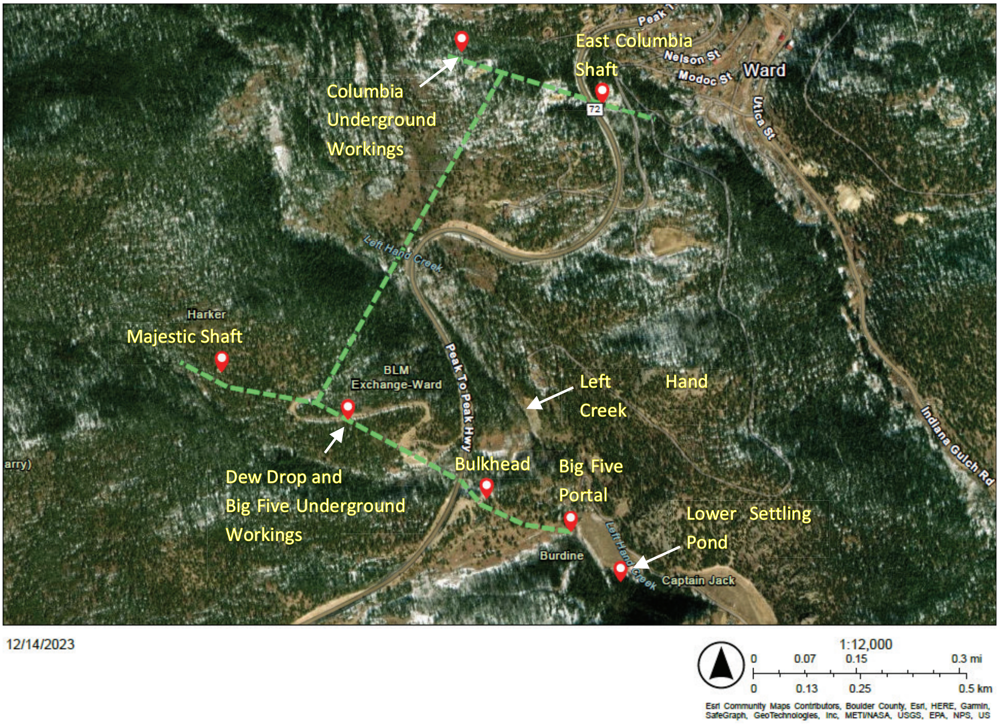

***Figure 1** Aerial view of underground workings at CJM*

settle and collect metal solids and remove excess sulfide and biochemical oxygen demand (BOD) from the effluent of the in-tunnel system. To promote neutralization and metal sulfide precipitation, the impounded water is periodically dosed with organic carbon (methanol, starch, molasses), sludge from prior lime treatment (containing residual alkalinity), sodium hydroxide and micronized lime at the location marked "Dew Drop and Big Five Underground Workings" (fig. 1) (EPA 2022). Water is recirculated within the mine pool to mix the amendments. During initial operation of the in-tunnel treatment system without organic carbon amendments in 2018, impounded water behind the bulkhead raised quickly and experienced negative water quality changes (lower pH and elevated metals concentrations) in the discharge (CDPHE et. al 2019). This led to an interim treatment of the water by an external lime-based system (EPA 2022). The interim lime treatment system is currently used to ensure the water from the in-tunnel treatment system has adequate pH adjustment and aeration before the effluent is discharged to settling ponds, and subsequently to Left Hand Creek.

Elizabeth Mine Superfund Site

The PTS at the Elizabeth Mine treats water from several drains within the buttress of Tailings Pile 1. The system consists of an anoxic limestone drain (ALD), which adds alkalinity, a settling pond (SP) where ALD effluent, low iron-loading drains, and drains having dissolved oxygen (DO) greater than about 2 mg/L mix, a vertical flow pond (VFP), and two constructed wetlands. The VFP adds additional alkalinity to the water and has a sulfate-reducing component that removes iron as a sulfide. The first wetland follows the SP and settles out additional iron that has been oxidized either in the SP or in the wetland. The second wetland oxidizes and settles out any iron that remains after the VFP, adds DO, removes BOD, and decreases hydrogen sulfide produced in the VFP. There is a ≈ 5 m cascade following the wetland prior to the treated water entering the Copperas Brook, which is the compliance monitoring location for the state. The cascade

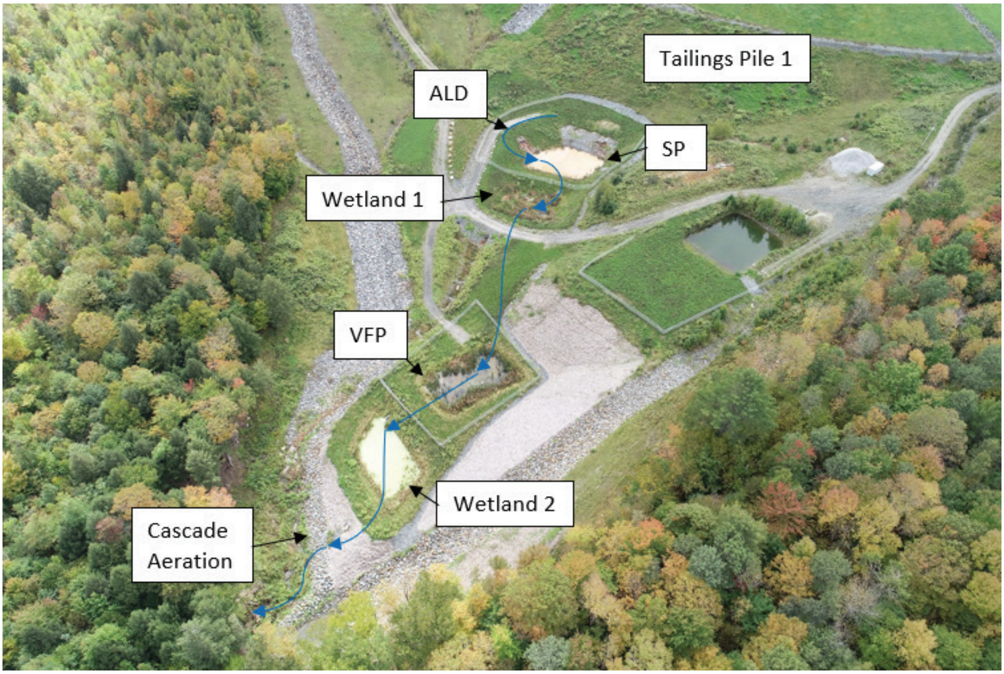

***Figure 2** Aerial view of the PTS at Elizabeth Mine Superfund site (July 2022). Direction of flow is indicated with blue arrows*

serves to add additional DO and remove residual hydrogen sulfide. The annotated aerial photograph in (fig. 2) shows the passive treatment components and the direction of flow through the system.

The system is designed to be completely passive, with little maintenance projected for ten years. Initial performance monitoring results show the constructed PTS consistently decreases iron concentrations by 99%. Additionally, preliminary results from samples taken from the discharge of the PTS showed that iron concentrations in effluent were consistently reduced from ≈ 150 mg/L to below 1 mg/L (Hathaway et al. 2021).

Lessons Learned

CJM Superfund Site

Several lessons learned were derived from the full scale, multi-year implementation of the demonstration. First, understanding the locations, mechanisms and quantity of sources of water entering any mine workings is important in designing an in-tunnel treatment system to achieve predictable performance. Source controls to reduce surface water and groundwater inflows are essential design features for future in-tunnel treatment systems. Uncontrolled inflow can result in high seasonal variability of water flow and mine pool levels which also affects water geochemistry and can reduce residence time for treatment. Although the site team initially used electrical resistivity tomography to survey the tunnel, and no meaningful water exchange with the surrounding rock was identified, inflowing water from surface and groundwater sources influenced retention times within the in-tunnel bioreactor, and subsequently treatment effectiveness. Naturally occuring environmental tracer studies were found to be a more effective method of determining the sources of water into the system (meteoric vs deep) (Newman et al. 2023). Second, the mine pool stratification proved to be a challenge for delivery of the amendments and monitoring the performance of the system, resulting in extra costs and longer time spent in the field. Caustic soda appeared as a spike in the pH at the bottom of the mine pool profile, but did not register in the top 3 m, where the water quality readings were originally taken. Ultimately, the in-tunnel treatment system was extended ≈ 244 m (800 ft) further upgradient of the bulkhead than the original 274 m (900 ft) in-bye to allow for adequate mixing, residence time, and treatment volume (Mahoney et al. 2019). The in-tunnel treatment system reduces most metals and acidity loading, but has increased the concentration of iron and manganese in the tunnel discharge. Water quality standards are currently being met in Left Hand Creek for all metals including iron and manganese due to active aeration and settling (EPA 2022). The addition of a passive ex-situ polishing component (passive aeration and settling) is planned to ensure consistent performance meeting the remedial action objectives and water quality standards with less energy requirement.

Elizabeth Mine Superfund Site

A few lessons have been learned from preliminary data since the beginning of the demonstration monitoring in March 2021. First, the vertical flow pond provides critical iron removal in the winter months when the temperature-dependent process efficiency of surface-exposed systems (like wetlands) declines. Second, subsurface porous systems may require more regular maintenance (every five years) to avoid short circuiting as preferential pathways develop. Third, the observed iron loading into each system component has been similar to the original engineering design calculations. Similar to the CJM treatment study, inflows from groundwater to the system may warrant further investigation and a tracer study is under development to investigate this potential.

Conclusions

Monitoring through the OSRTI's demonstration program has been completed for the CJM Superfund site, and they are developing a passive external polishing system. The Elizabeth Mine Superfund site demonstration monitoring is ongoing as of December 2023. Passive treatment at Elizabeth Mine was not feasible in the early years of site remediation due to the high iron loading and limited space to allow for a system of sufficient size to treat the iron load. The site is however, a good example of adapting over time to reach the desired long-term treatment. Only after other activities at the site resulted in decreased discharge and iron concentrations from Tailings Pile 1 was the site amenable to longer term passive treatment. Future years of seasonal data will allow a better understanding of how temperature and precipitation influence performance and longevity of each of the components within a primarily biologically-based PTS.

Assessing performance of an in-tunnel treatment is more difficult than assessing performance of a system open to the environment. Having unknown sources of flow into a tunnel or flows that vary seasonally make it more difficult for adequate residence time calculations and dosing of amendments. The project team developed innovative approaches to collecting data from the stratified mine pool. They also found that managing water level was a critical in-tunnel management strategy, which mitigated flushes of metal salts, and volume fluctuations. Based on the three years of monitoring, and volume control, they have developed a passive dosing system with a cost advantage over an active system.

The MIW Treatment Technology Demonstration Program has successfully facilitated knowledge transfer and collaboration between project managers in the Superfund program. As more demonstration projects join the MIW Treatment Technology Demonstration Program, the lessons learned from each will be shared and compared across sites to inform decision-making. Filling the critical data gaps in innovative MIW treatment (long term performance, seasonal variability, and waste generation) will aid in project planning, operation and management in the future.

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Disclaimer

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