# Acid Mine Drainage Source Control Program Design Investigation Upper Tenmile Creek Mining Area Superfund Site, Rimini, Montana

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**Abstract**
This presentation will describe the status of the acid mine drainage source control program at the Upper Tenmile Creek Mining Area Superfund Site in Montana. The Site contains approximately 150 abandoned mines. Remediation has not addressed mine-influenced water (MIW) from discharging adits.

Remediation of discharging adits is prioritized by contaminant loading of arsenic, cadmium, copper, lead, and/or zinc. MIW from three adits, the Susie, Lee Mountain, and Red Water, are considered Principal Threat Wastes by the United States Environmental Protection Agency (EPA). Principal threat wastes are highly toxic or highly mobile materials that cannot be contained in a reliable manner that present a significant risk to human health or the environment. Under Superfund Law, Principal Threat Wastes must be treated.

To reduce (or potentially eliminate) the need for active water treatment at these three adits, the design investigation is focused on identifying potential water infiltration sources with the goal of reducing or eliminating MIW. Initial findings show that the Susie discharge responds slowly or not at all to precipitation and stream flow changes indicating catchment-wide recharge. Discharge at the Lee Mountain adit responds quickly to precipitation indicating direct connections to the surface. Results of the investigation will be used to develop pilot infiltration reduction measures.

Key Words: adit discharge

## Introduction

The Upper Tenmile Creek Mining Area Site (see Figure 1) is a watershed scale Superfund site west of Helena, Montana, consisting of approximately 150 abandoned hard rock mines, and approximately 40 discharging adits. Remediation of discharging adits is prioritized by contaminant loading of arsenic, cadmium, copper, lead, and/or zinc. Mine-influenced water (MIW) from three adits, the Susie, Lee Mountain, and Red Water, are considered Principal Threat Wastes by the United States Environmental Protection Agency (EPA) (EPA 2002). Principal threat wastes are highly toxic or highly mobile materials that cannot be contained in a reliable manner that present a significant risk to human health or the environment. Under Superfund Law, Principal Threat Wastes must be treated (EPA 1990).


Figure 1: General Site Location

Based on water quality monitoring and a remedial investigation (USGS 2012; CDM 2001) water quality in Tenmile Creek has been impacted by the mine waste and acid mine drainage (AMD), with arsenic, cadmium, and zinc of most concern. Under EPA protocol, the site cleanup decision is called the selected remedy and is formalized in a Record of Decision (ROD) which was completed for the site in 2002 (EPA 2002). The ROD contained goals of controlling principal threat wastes and eventually attaining Federal and State aquatic and human health water quality standards in Tenmile Creek. The selected remedy for AMD including adit discharge is a four-phase approach to identify and implement source control options if possible, before committing to long-term passive or active treatment. The phases include:

1. Initial design investigations consisting of an overall assessment of the potential to achieve significant O&M cost savings through source controls to reduce the volume of AMD from individual mines.
2. Source control and flow reduction design and pilot studies at certain mine sites to demonstrate source control and flow reduction techniques.
3. Source control and flow reduction implementation at full-scale at specific mine sites.
4. Design and construction of appropriate AMD treatment facilities (either passive/biological or physical/chemical systems) where necessary to meet State of Montana ambient water quality standards in receiving waters.

The Upper Valley Forge/Susie and Lee Mountain mines (see Figure 2) were identified as two of the largest sources of contaminant loading to the watershed (CDM 2007). These mines were carried forward into the first phase of the source control process to perform an in-depth reconnaissance of the mine site features and hydrology of these two sites. In addition, historic data (workings maps, photographs, and mine inspection reports) were collected, compiled, and analyzed to confirm or validate field findings. This information is to be used in the planning of pilot-scale source control efforts to minimize discharge of MIW from the adits.

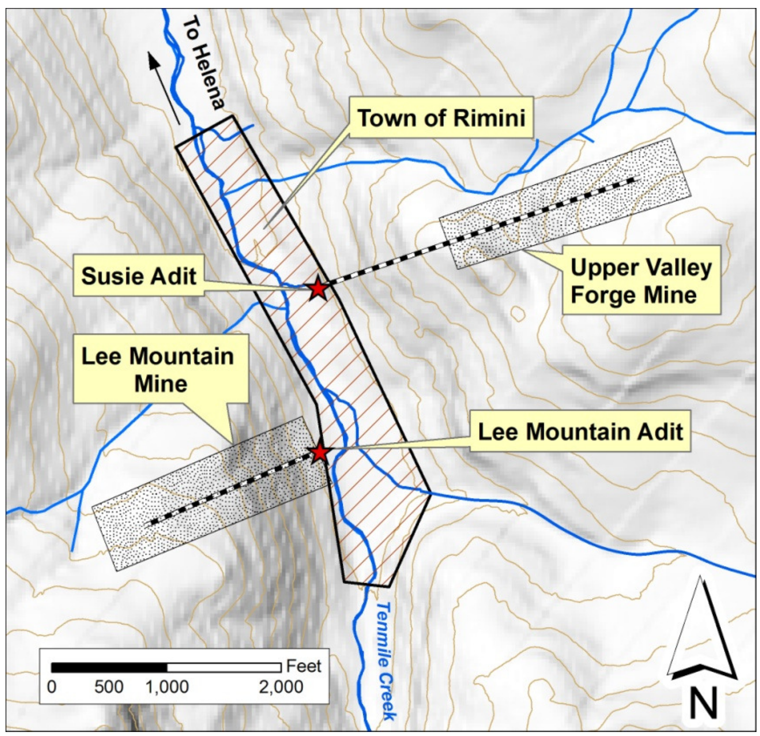

Figure 2: Mine and Adit Locations

This paper will present the findings of the 2010-2011 source control investigations at these two mines. The two mines make an interesting case study because, even though they are located approximately 1,500 feet apart, they may require different source control strategies. A photo of the Susie adit is shown in Figure 3 and a photo of the Lee Mountain adit is shown in Figure 4.

Figure 3: Susie Adit

Figure4: Lee Mountain Adit

**Adit Discharge Monitoring**
Monitoring of the adits discharge was conducted from 2002 to 2007 prior to initiation of the source control investigation. Typical water quality and flow rates for the two adits are presented in Table 1 (these data are not all-inclusive). As the data show, water quality is poor, with low pH and high concentrations of metals and arsenic (CDM 2007).

Table 1: Representative water quality from the Susie and Lee Mountain adit discharges

| | **Susie/Upper Valley Forge** | **Lee Mountain** |
|---|---|---|
| **Discharge** | 5 to 10 gpm | 2 to 8 gpm |
| **pH** | 3.5 to 4.3 | 2.5 to 3.0 |
| **Dissolved Iron** | 150 to 200 mg/L | 250 mg/L |
| **Dissolved Aluminum** | 1 mg/L | 20 mg/L |
| **Dissolved Arsenic** | 10 to 20 mg/L | 25 to 30 mg/L |
| **Dissolved Cadmium** | 0.2 mg/L | 0.5 to 1 mg/L |
| **Dissolved Zinc** | 30 mg/L | 50-80 mg/L |

gpm = gallons per minute; mg/L = milligrams per Liter

**Historic Mine Workings**
Historic mine workings maps of the Upper Valley Forge mine/Susie adit and Lee Mountain mine were obtained from the Anaconda Geological Documents collection maintained by the University of Wyoming (University of Wyoming 2011) and are shown on Figures 5 and 6.

The 900-foot level of the Upper Valley Forge mapped mine workings extends toward the west to the Susie adit opening (Figure 5). Importantly, the connection between the Upper Valley Forge workings and the 900-foot level tunnel to the Susie adit serves as a drain for the ground water in the workings. Because of the tunnel distance and depth, the discharge appears to reflect long-term hydrologic fluctuations. This is consistent with the discharge measurements, which showed little immediate correlation with precipitation events.

The shallower, upper level workings of the Upper Valley Forge appear to extend east. Specific connections with the upper workings were not detailed on the available plans. It is unknown how much additional development occurred in the Upper Valley Forge mine after the drawings were completed.

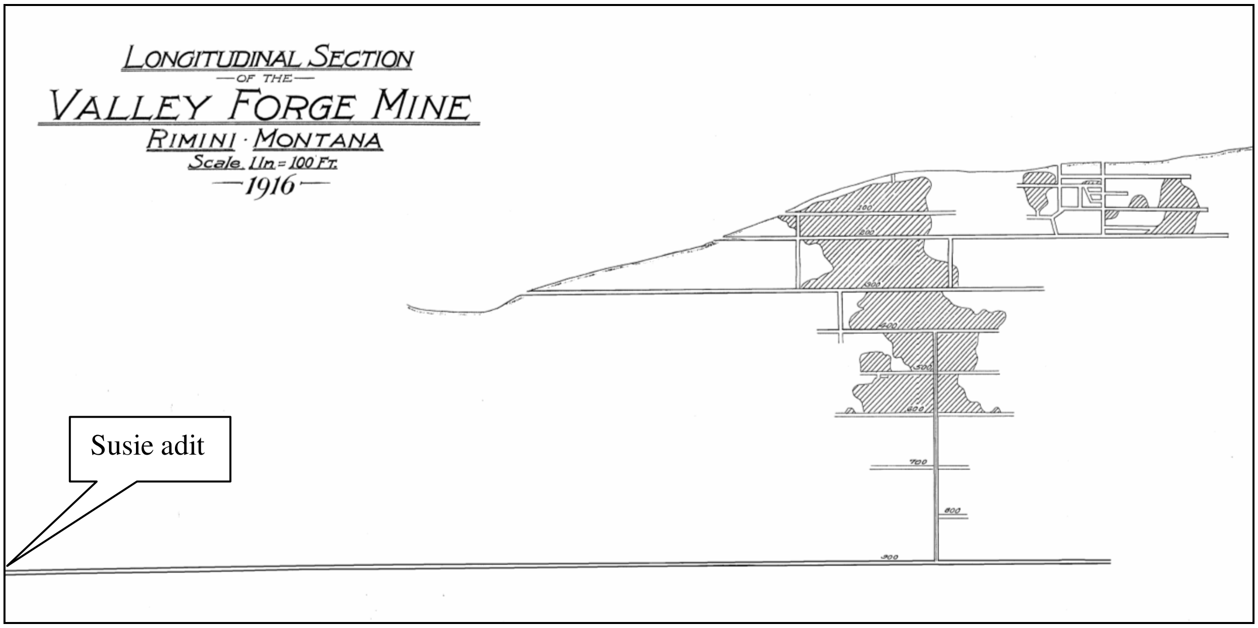


Figure 5: Cross-section of the Upper Valley Forge mine from 1916. Not to scale.

Available maps of the Lee Mountain workings dated 1918 were reviewed. Figure 6 is an historic map showing a cross-sectional view of the underground workings.

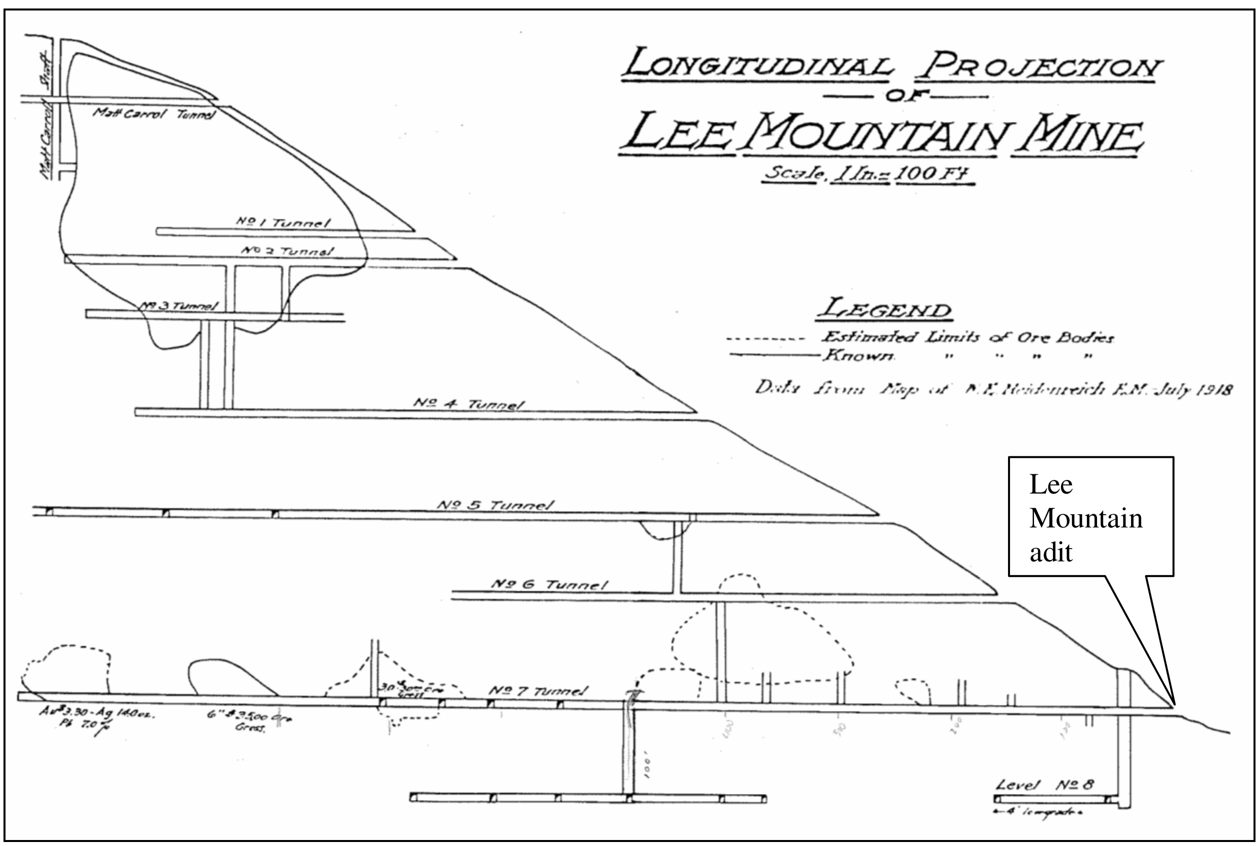


Figure 6: Cross-section of the Lee Mountain Mine, 1918. Not to scale.

Cross-section views for the mine workings depict seven adits that open to the face of Lee Mountain. Plan view maps of the Lee Mountain mine are limited to the No. 7 tunnel (the discharging adit), which at the time the map was drawn, appears to extend approximately over 1,000 feet into the mountain. The adits and shafts shown on the drawing indicate significant connection of the mine workings to the ground surface.

**MIW Monitoring**

Discharge measurements at each of the adits were made periodically (every few days) using a bucket and stopwatch through the spring and summer of 2010 and were compared to area precipitation and stream flow in Tenmile Creek. Results from the Susie adit are presented in Figure 3, while results from the Lee Mountain adit are shown in Figure 4. Based on a nearby USGS gaging station (Tenmile Creek near Rimini MT, USGS 2012), annual peak flow in Tenmile Creek occurred in early June and flow decreased over the summer. Short-term discharge increases in Tenmile Creek generally correlate to precipitation events recorded at the Helena Airport 15 miles to the northeast exceeding one-half inch.

A comparison of Susie Adit discharge to Tenmile Creek discharge and precipitation (Figure 7) shows little correlation indicating the Susie Mine workings are not directly affected by precipitation events or changes in stream discharge. The lowest working level of the Upper Valley Forge mine is the Susie adit which is above the stream bed of Tenmile Creek. The source of the Susie adit discharge is more likely to be ground water entering portions of the upper mine workings and flowing down to the adit level.

A comparison of Lee Mountain mine discharge to precipitation and Tenmile Creek discharge (Figure 8) shows that increases in mine discharge occur soon after precipitation events and increases in Tenmile Creek discharge, indicating that the mine workings are directly impacted by precipitation runoff and/or infiltration. The Lee Mountain adit level is above the Tenmile Creek streambed, but additional workings extend below the streambed elevation. Therefore, changes in stream flow may affect mine water levels.

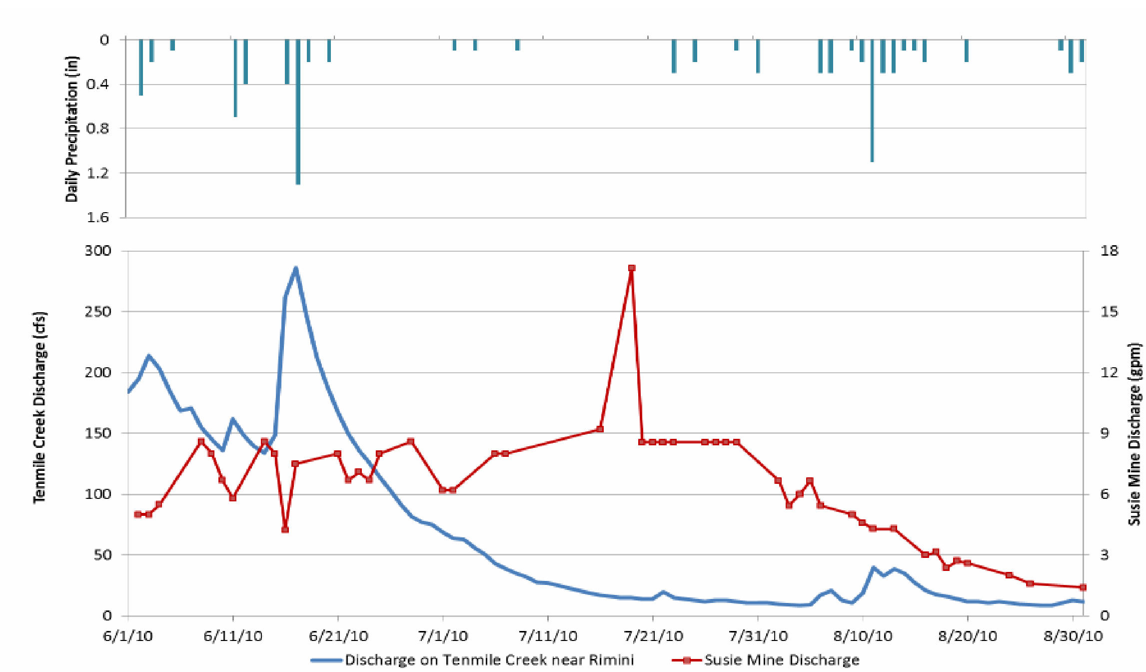


Figure 7: Susie Adit discharge compared to precipitation

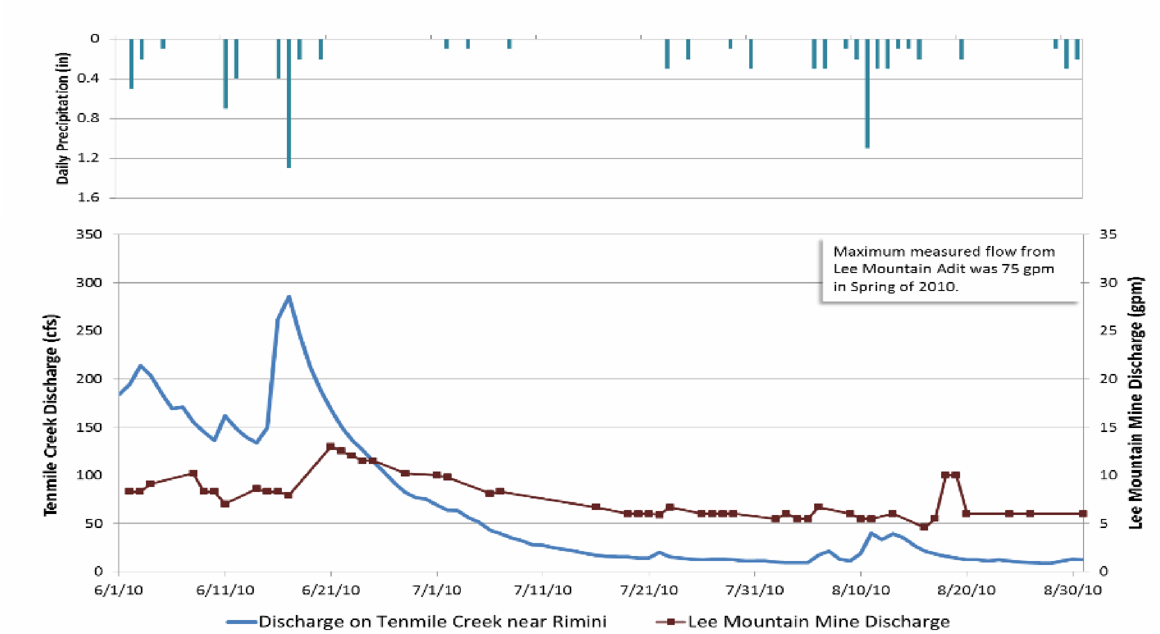

Figure 8: Lee Mountain Adit discharge compared to precipitation

In addition to discharge, specific conductivity (SC) and pH were measured at the Susie and Lee Mountain adits. Figures 9 and 10 show these parameters as a function of discharge at the two adits.

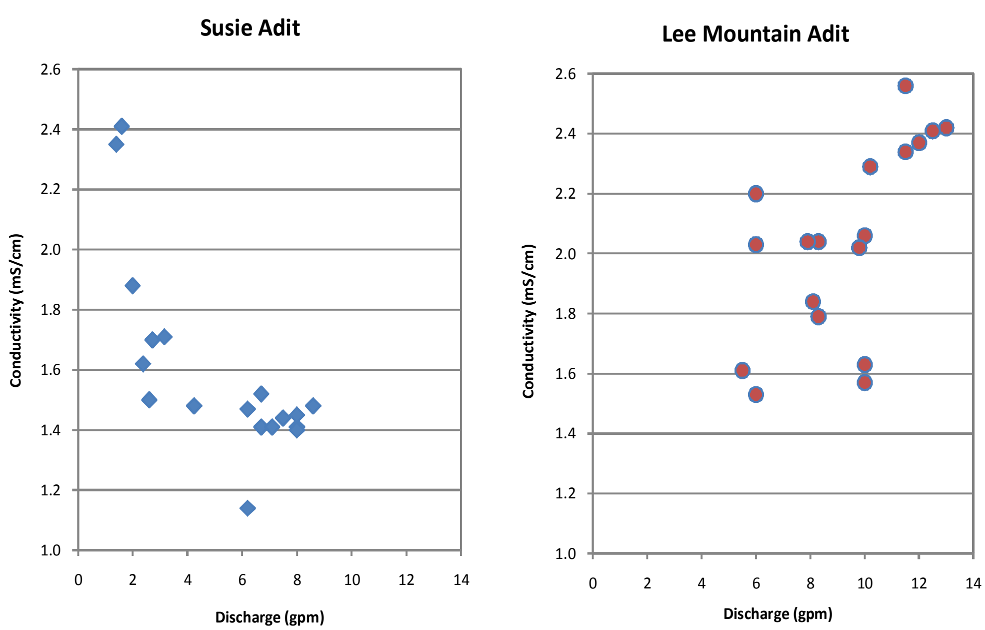

Figure 9: Susie and Lee Mountain Adit specific conductivity as a function of discharge.

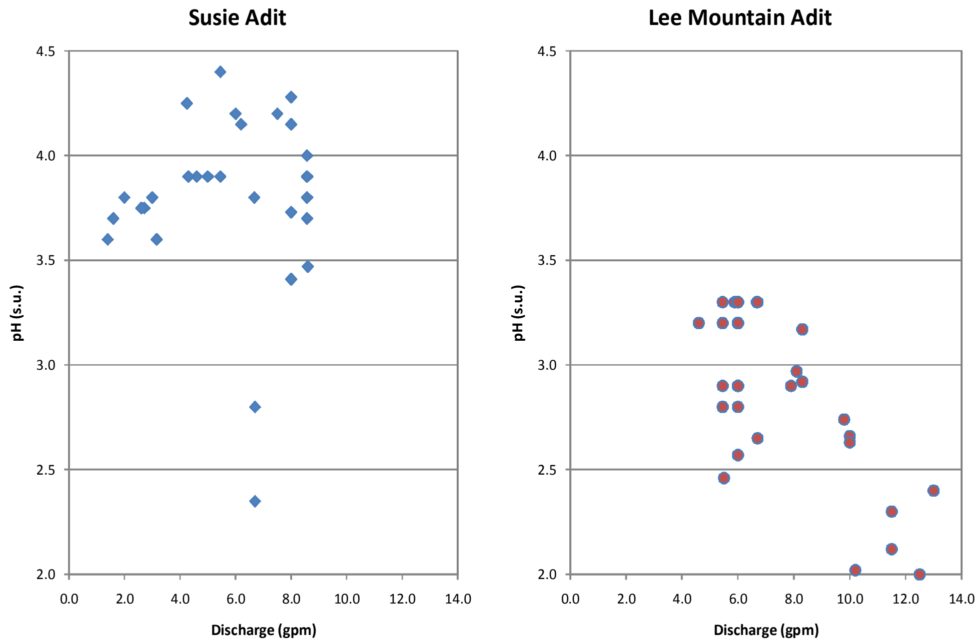

Figure 10: Susie and Lee Mountain Adit pH as a function of discharge.

For the Susie adit, specific conductivity is highest at low flow rates and appears to decrease with increasing flow rates. Specific conductivity becomes more constant at discharge rates exceeding 5 gpm. This indicates that the higher flows dilute the specific conductivity. Measured pH in the Susie adit discharge does not show a trend with the discharge rate and remains below 4.5 at all discharge rates. Because the pH does not respond to changes in flow, it flows do not affect the degree of contact between the acid-generating workings and the influent water, or the presence of buffering minerals.

In contrast, at the Lee Mountain adit, both pH and specific conductivity measurements indicate a worsening of water quality as the discharge increases. In other words, the pH decreases (becomes more acidic) and specific conductivity increases (more dissolved ions) when discharge increases. This information suggests that increased flows likely result in more contact with AMD-generating minerals in the mine workings.

The numerous surface openings of the Lee Mountain mine and overall shallowness of the workings result in infiltration of precipitation that manifests as increased flows from the discharging adit. Poorer water quality accompanies the increased flows. No perennial or ephemeral drainages were found that obviously contribute to local ground water flow. Therefore, the overall regional infiltration of precipitation appears to be the source of water in the Lee Mountain mine workings.

**Hydrologic Investigation**

In conjunction with the flow and water quality monitoring, hydrologic investigations were conducted to determine if nearby perennial or ephemeral streams were flowing into the mine workings. Stream gaging was used to evaluate tributary flows and locate reaches where surface water is lost to ground water in the vicinity of the workings. One losing reach was found above the Upper Valley Forge and was subjected to further investigation. More detailed gaging later determined that the stream regained the lost flow further downstream. Stream gaging in a tributary near the Lee Mountain mine found no losing stream reaches.

In 2011, a dye tracer study was undertaken to evaluate ground water flow paths at the Upper Valley Forge mine. Three different locations were evaluated for infiltration from surface water to the mine workings:

the losing reach identified during stream gaging and two small ponds on the mine site. Each location was injected with a different dye and monitoring was conducted in the perennial stream adjacent to the mine and the Susie adit.

For the losing reach of the tributary, Eosine tracer was injected into the tributary over a period of several days. The tributary was dry downstream of the injection point indicating that all of the surface water and tracer was lost to ground water. Samples were collected at the mouth of the tributary and the tracer was detected indicating continuity of flow in the stream through the losing reach and past the mine workings. Samples were collected of the Susie adit discharge for several months and the tracer was not detected. This indicates that the losing reach of the tributary does not enter the Upper Valley Forge mine workings and exit at the Susie adit.

Figure 11: Injecting Rhodamine WT dye into a small pond at the Upper Valley Forge Mine

For the two ponds at the Upper Valley Forge mine, two different tracers (Fluoroscein and Rhodamine WT) were used. Each pond received a different tracer in a single dose (See Figure 11). The ponds were stirred to ensure even distribution over the water body. The pond receiving Fluoroscein was covered to minimize exposure to sunlight (See Figure 12).

The Susie adit was monitored for several months for the presence of all three dyes. No dyes were detected in the adit indicating the connection between surface water at the mine and the adit is not significant or very slow.

**Discussion**

The purpose of the first phase of the source control programs was to conduct initial design investigations consisting of an overall assessment of the potential to achieve significant O&M cost savings through source controls to reduce the volume of AMD from individual mines. Based on the findings of the investigations, different approaches to source control may be necessary at these two adits.

Figure 12: Plastic coving on a small pond following application of Fluorescein dye

At the Susie adit, surface water at the

site may infiltrate into the mine workings and control of the infiltration was a potential action. Each surface water body was investigated using stream gaging and dye tracing. No evidence of infiltration of this surface water was found in water discharging from the Susie adit indicating that infiltration controls installed at these locations are not likely to affect the volume of AMD.

Given that infiltration reduction is not a viable control measure at the Upper Valley Forge mine, installation of a bulkhead in the Susie adit may be a potential solution. This would limit or eliminate discharge directly from the adit. If it were feasible to safely construct a bulkhead, ground water should flood the adit and potentially much of the historic workings and reduce AMD generation due to reduced contact with air. Additional investigation is needed to evaluate the number and potential locations of bulkheads needed for adequate sealing of the adit.

Hydrologic investigations at the Lee Mountain mine indicated that no surface water bodies were found that could be infiltrating the mine workings. The source of the water in the mine is apparently related to direct infiltration of precipitation. Given the size and steepness of the mine site, installation of a cap is impractical. No other infiltration reduction alternatives have been considered.

At the Lee Mountain mine, a bulkhead in the adit may not result in adequate control of water because the interconnectivity of the mine workings with the surface may redirect flow to a different level rather than preventing discharge. Sealing of the mine openings to prevent air and water infiltration is expected to reduce, but not eliminate AMD and the permanence of such seals is questionable. As a result, source control options appear limited and it seems likely that collection and treatment of AMD may be unavoidable.

Because of their close proximity, a treatment system could be designed to handle the combined flows of both adits. If treatment for the Lee Mountain adit discharge is deemed necessary, the cost of adding the discharge from the Susie adit will be compared to installation of bulkheads to control AMD at that site. Furthermore, for the Susie adit, the effectiveness of the bulkheads is uncertain due to unknown connections with other abandoned mines on the same mountainside.

**Conclusions**

Based on surface observations, hydrologic investigations and dye tracing studies, prevention of infiltration of surface water into mine workings at the Upper Valley Forge and Lee Mountain mine sites does not have an easy engineering solution. Water discharging at the Susie adit appears to have a regional ground water source and water in the Lee Mountain adit appears to have a regional precipitation source, neither of which are preventable. This leaves installation of bulkheads as an alternative to control discharge of MIW. This has merit at the Susie adit due to its position at the bottom of the workings. The success of bulkheads at the Lee Mountain mine is questionable due to the multiple interconnected levels and connections to the surface. It is anticipated that both of these mine sites will be advanced to Phase 2 of the source control program with further evaluation of bulkheads.

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**Further Information**
Further information on the remediation program underway at Tenmile Superfund site can be obtained at:

http://www.epa.gov/region8/superfund/mt/upper_ten/index.html