London Extension Tunnel Water Treatment System
Acid Mine Drainage Treatment Plants do NOT have to cost Millions to construct and operate[1]

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Abstract. Water treatment at the London Extension Tunnel, an historic gold mine located in the central Colorado Rockies, is an example of cooperation between the mine permit holder, the water rights holder, the Colorado Department of Public Health and Environment (CDPHE), the Colorado Division of Reclamation, Mining and Safety (CDRMS) and Colorado School of Mines (CSM), using US Environmental Protection Agency (USEPA) funding to achieve the two phase goals of a) demonstrating a simple and inexpensive water treatment plant, and b) reducing the metals loading on South Mosquito Creek.

The treatment system removes from 89% to 99% of the heavy metals when the effluent pH is maintained between 9.5 and 10.0. Zinc removal alone averages approximately 20 pounds per day. Total construction cost for the treatment system was less than $150,000. System maintenance and operation is estimated to be $10,000 annually, plus labor costs. Numerous modifications have been made to the system to operate more efficiently and reliably at an elevation of 11,300 feet. Cement Kiln dust has been proven to be a cost-efficient neutralizing agent compared to other commercially available neutralizing agents.

This paper will explain the goals, funding sources, construction limitations, operational constraints, and demonstrated metals reduction accomplished in this cheap-to-build-and-operate demonstration project built and operated all year above 11,000 feet elevation.

This plant was constructed by Frontier Environmental Services, LLC. under a contract with the Colorado Division of Reclamation, Mining and Safety, formerly Colorado Division of Minerals and Geology (CDMG), and subsequently operated by CDRMS staff year-round for two years.

Additional Key Words: water pollution, heavy metal contamination

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Introduction

The London Extension Nonpoint Source Project, also referred to as the London Extension Tunnel water treatment system, is located in the Mosquito Creek watershed of Park County, approximately seven miles northwest of Fairplay, Colorado and 15 miles south of Breckenridge (Figure 1). The London Extension mine is located in the NW ¼ of Section 15, Township 9 South, Range 78 West in the headwaters of South Mosquito Creek, a tributary to Mosquito Creek. Previous studies by NUS Corportation and Colorado Department of Public Health and Environment (CDPHE) indicated that aquatic life in South Mosquito Creek is essentially nonexistent and that aquatic life in adjoining Mosquito Creek is severely impacted. This is a result of the poor water quality and degradation of the habitat from extensive historic mining. CDPHE identified five sources of contamination in the South Mosquito and Mosquito Creek drainage basins during a study in August 1988. These sources of contamination are: 1) Montgomery (Alma-Betts) Mill tailings; 2) Historic London Mine tailings; 3) Butte tailings; 4) drainage from the abandoned London Extension Tunnel; and 5) the North London Mill Tailings. The London Extension Tunnel is the largest single source of metals contamination to the Mosquito Creek watershed. The draining London Extension Tunnel was originally included in the South Mosquito Creek Nonpoint Source project developed by the Colorado Division of Reclamation, Mining, and Safety (DRMS).

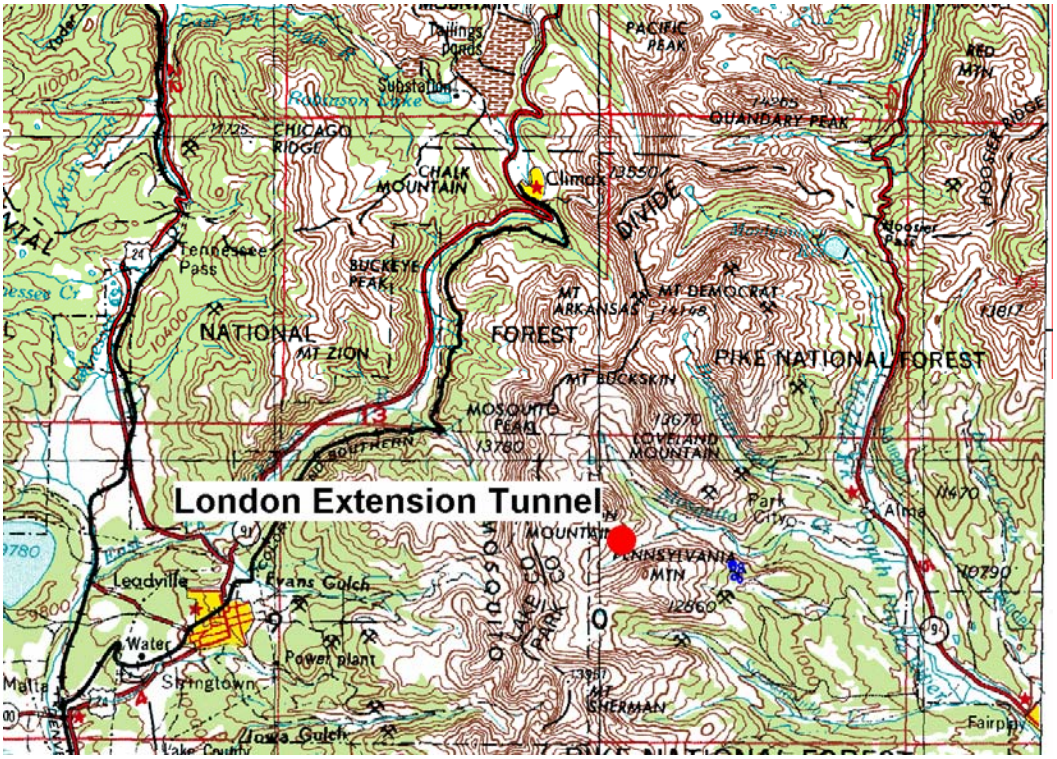

Figure 1. Location Map of London Extension Tunnel (not to scale).

Location

The London Extension Tunnel is located near the headwaters of South Mosquito Creek (Figure 1). The mine drainage from the London Extension Tunnel flows into No Name Creek approximately 500 feet before its confluence with South Mosquito Creek. South Mosquito Creek drains an area approximately 4.4 square miles on the east side of the Mosquito Range. South Mosquito Creek joins Mosquito Creek about three miles from its source and ultimately flows into the Middle Fork of the South Platte River north of Fairplay, Colorado. South Mosquito Creek is classified as a Class 1 cold aquatic life stream. It has a Class 1 recreation designation. South Mosquito Creek does not meet the water quality criteria for its designated use. There are no known recreational uses of South Mosquito Creek. Fish are not present throughout most of South Mosquito Creek and its tributaries. The absence of fish above the mining area where the water quality and stream habitat are unaffected may indicate that a winter kill has occurred and fish cannot access these upper areas now because of the poor water quality and degraded habitat in the mining areas.

The London Extension Mine is at an elevation of approximately 11,600 feet. The site is bordered on the west by the Mosquito Range, which reaches elevations of 13,700 feet. The Continental Divide lies about six miles north of the site, trending east-west. The town of South Park is located to the east at an elevation of about 10,000 feet. The nearest and most applicable weather station to the London Extension Mine is located at Climax. This station is about seven miles north-northwest of the site at an elevation of 11,300 feet. Because of the similarity in elevations and proximity of location, data from Climax are thought to provide a good estimate of the conditions at the South Mosquito Creek site. The winter season is cold and harsh in the South Mosquito Creek area and lasts from about November to April. Snowfall depths have been recorded at as much as 105 inches per month. Average annual snowfall is about 279 inches. Maximum and minimum temperatures for an eight-year period range from -25° F to 75° F. Average annual precipitation is about 23 inches. Snowmelt is heaviest during the months of May, June and July, but hail and snow flurries are also common during these months.

The South Mosquito Creek site lies on the eastern flank of the north-trending Sawatch Uplift which encompasses the Mosquito Range. Three major reverse faults cut the beds on the east side of the Mosquito Range. The largest of these is the London Fault with a total offset of approximately 3,000 feet.

Land Use

Land use in the immediate vicinity is mining at the recently active London Mine (Water Tunnel). The surrounding area is used primarily for recreation and by wildlife within the Pike National Forest. Wetlands are found along South Mosquito Creek above the Project Site and at American Flats on the No Name

Creek drainage basin. The area along No Name Creek and South Mosquito Creek downstream of the project area has been drastically disturbed by past mining operations.

History

The London gold vein was discovered in 1873 and mining began at the North London portal in 1875. The primary ore body is located along the London Fault, which is a reverse fault trending approximately N 30° W and dipping from 60° northeast to vertical. The major production came from contact zones between Tertiary intrusives and the Pennsylvanian-age Weber Formation and Mississippian-age Leadville Limestone. The total gross production of gold and silver until 1931 was recorded at almost $8,000,000. In the 1970's through the early 1990's, there were several attempts to mine in the lowest tunnel of the complex.

The London Mine was an extensive mining operation. There are four main adits to the mine and one shaft. The north London Mine is located approximately two miles north of the London Extension Tunnel at an elevation of 12,100 feet. The American Shaft is located about one quarter mile north of the London Extension Tunnel at an elevation of 12,200 feet. The Water Tunnel level is located approximately 500 feet southeast of the London Extension tunnel at an elevation of 11,500 feet. The Water Tunnel workings are all located below the London Extension level. The American Shaft supplies natural ventilation to all the workings of the London Extension and Water Tunnel levels.

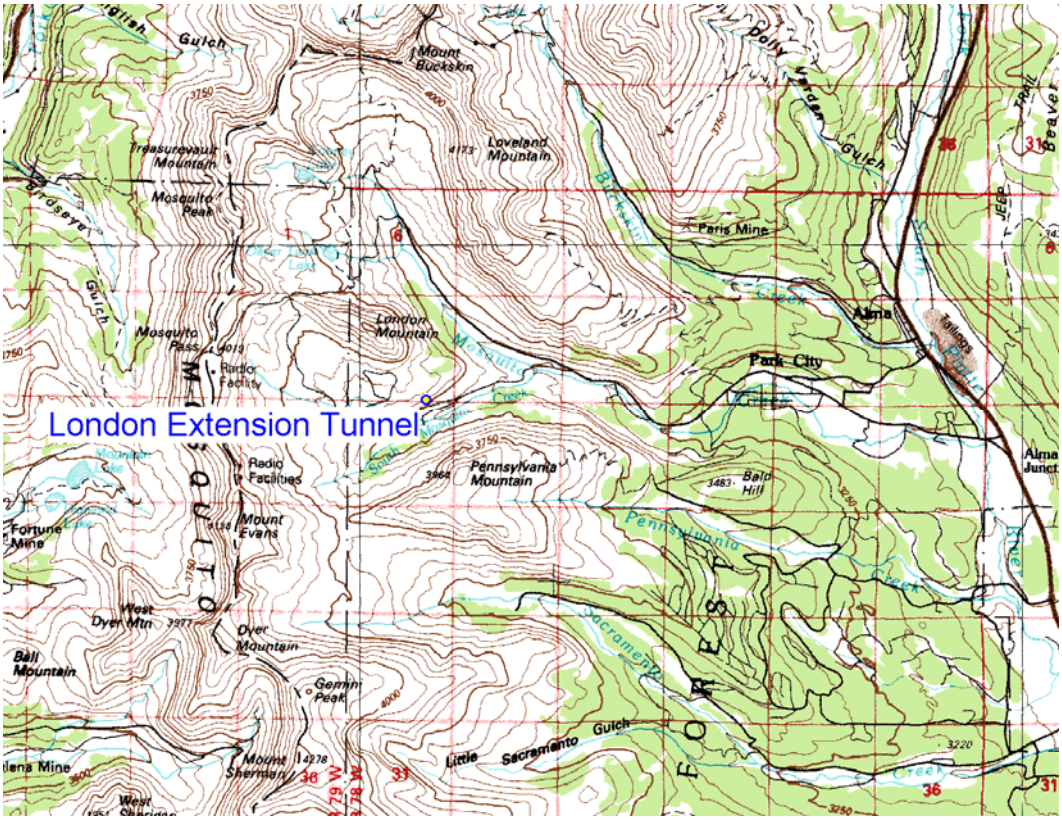

Figure 2. Upper Portion of Mosquito Creek Watershed (not to scale).

Project Overview

In 1991, and again in 1993, the accessible portions of the London Extension were investigated by DRMS staff. The investigations showed that approximately 90% of the heavy metals in the London Extension mine drainage came from the mine workings above the Extension level in only 5% of the average flow. The high metal drainage from the upper workings flowed into the London Extension from a series of raises connecting the levels.

When the London Extension project was initiated in 1993, it was thought that the "good" and "bad" water could be segregated inside the mine. The high metal portion would then amount to approximately 5 gpm, which is much simpler to treat than the 15 to 160 gpm flow. In 1993, DRMS hired two miners to channelize the flow to determine where metals entered the mine drainage. A mass balance sampling was completed in November 1993. However, CDPHE halted all work on the project immediately after the sampling was done, and due to funding constraints, the samples were not analyzed. The site remained idle until 1997, when CDPHE persuaded the mine owner to accept a permit to treat the London Extension drainage.

In 1997, the mine workings were again investigated by DRMS to complete the mass balance sampling. Deterioration of the ribs (sides) and buildup of metal

sludge destroyed virtually all the work done in 1993 to channelize the flow. Sampling and flow measurements had been done at 12 locations inside the mine in 1993. Flows could be measured in only four locations in 1997. Investigation of the mine workings also showed that several locations near the mine entrance were becoming unstable, due to the support timbers becoming rotten. Because of the instability of the mine workings, it was decided that segregation of the "good" and "bad" water would likely lead to future problems in maintaining the drainage lines.

Following the investigations, it was determined that the entire mine drainage would have to be treated outside the mine. Mr. Paul Seeley of Cenibark International was contracted to conduct bench scale tests to determine what level of treatment was necessary to meet the water quality standards, to determine what reagent was most economical, and to design a neutralization treatment system. The design selected Cement Kiln Dust (CKD).

System Overview

The London Extension treatment plant consists of a collection system inside the mine including a partial bulkhead approximately 30 inches high constructed of rock and mortar (Figure 3). There are two drains in the partial bulkhead, a drain valve to allow flushing the sediment that builds up behind the partial bulkhead out to a settling pond near the portal; the other a six-inch diameter PVC discharge pipeline that conducts the water to the mixing tank.

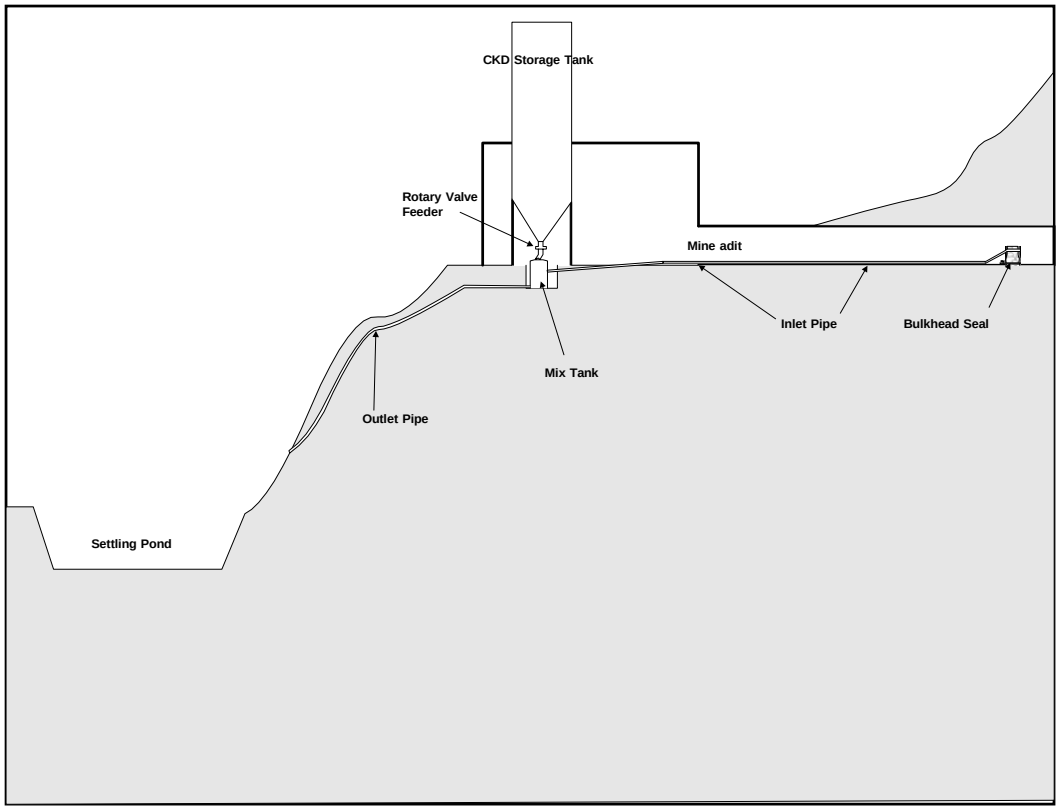

Figure 3. Profile view of treatment system (not to scale).

In the mixing tank CKD is introduced to the mine water and mixed by an electrically powered stirrer. CKD is metered out of the bottom of the CKD tank by an electrically powered variable speed rotary vane feeder. The CKD tank is vibrated periodically by an electrical vibrator that is controlled by a timer. The CKD addition system was originally to be controlled by a pH probe located 20 feet downstream of the mixing tank connected to a controller that would adjust the feed rate of the vane feeder.

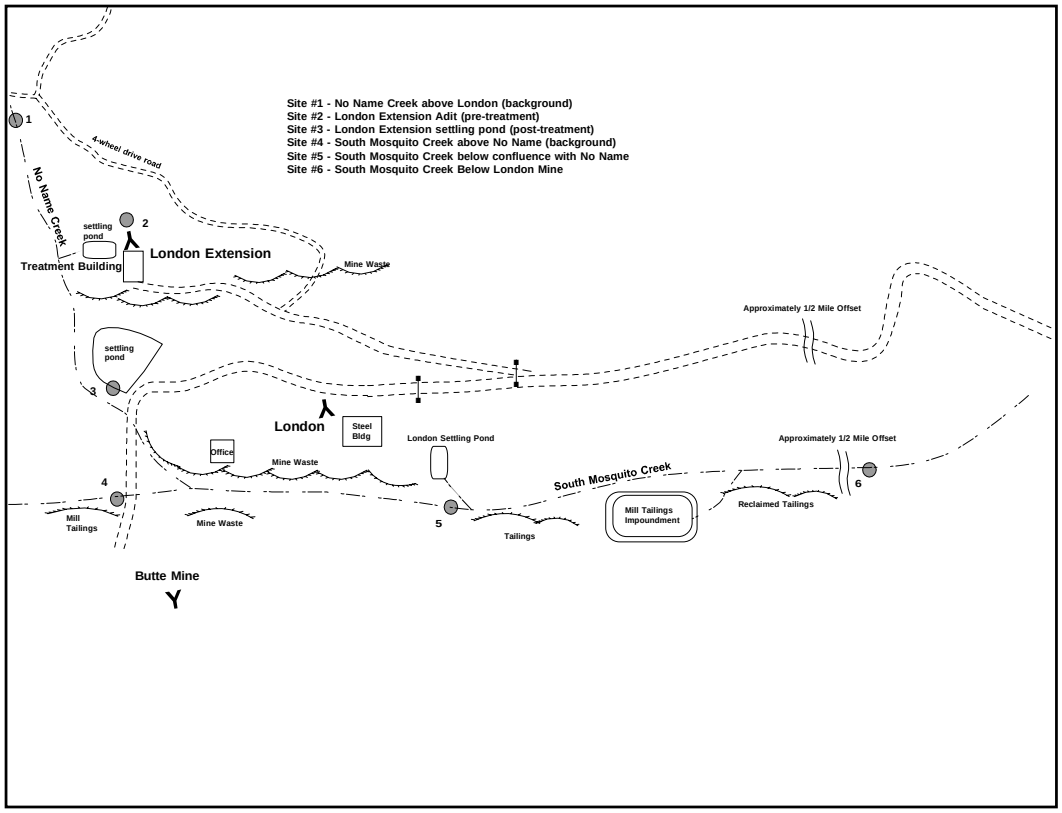

Figure 4. Plan view of London Extension with water sampling locations (not to scale).

The mixture of CKD and mine water exits the mixing tank and flows down to the settling pond in a six-inch high density polyethylene (HDPE) pipeline that is buried on the steep hillside. Mixing the CKD and mine water and allowing it to settle allows the basic CKD to bind to the acidic metal-oxides and settle to the bottom of the pond. The neutralization occurs as metals precipitate as hydroxides, oxides, and carbonates.

Periodically, the pond is flushed out into the drying pond and the metal laden CKD is allowed to dry. Once dry, the CKD is loaded and transported to a nearby disposal area shown on Figure 4.

DRMS contracting process began in July 1997 including the design prepared by Mr. Seeley. Interested contractors were shown the project site in late July 1997, and bids were opened on August 5, 1997. The low bid was in excess of the DRMS budget for the project, necessitating negotiation of the price downward to $92,541 by allowing the low bidder to substitute a used CKD tank and to eliminate one of the two proposed settling ponds.

Construction of the London Extension water treatment system began in early October 1997 and was largely completed in mid December, when snow became too deep to allow work to continue. In early June 1998 the system was

completed with some minor changes to the original contract. The treatment system was tested for short periods of time during the summer and fall of 1998 while discharge permit negotiations occurred. Several years of permit negotiations were necessary to find an entity to hold the discharge permit. Following receipt of a letter from Mr. Dave Akers, Manager of the Water Quality Protection Section of the Water Quality Control Division in late September 2002 authorizing DRMS to operate the London Extension treatment system, DRMS initiated startup procedures. The system was started on October 3, 2002, and operated by DRMS through the fall of 2004.

The owner of the mine property and water rights has sold a portion of the water rights to a developer in the Denver Metropolitan area and has acquired a non-point source permit with CDPHE which requires operation of the water treatment system. The developer has engaged a consultant to modify the plant and to operate the system, removing DRMS as operator.

System Performance

Since the treatment system had been dormant for the four year period of discharge permit negotiations, it required significant work to begin running properly. The pipeline leading from the partial bulkhead underground had plugged with iron precipitate, causing the discharge to overtop the partial bulkhead and flow along the floor of the drift. The bypass pipe had also plugged, and iron precipitate had built up behind the partial bulkhead to the top. Approximately five tons of CKD had been left in the tank over the ensuing four years and had caked and would not flow into the feeder. In all, three weeks were required to begin normal operation of the system.

Operation of the system began to highlight several areas that caused the system to malfunction. The first was the pH control that was to automate the system. Oxides of iron blinded the pH probe within an hour under most operating conditions. In no case did it operate through a day. The feed rate was set manually based upon pH readings taken from the tank through the time DRMS operated the system.

The next malfunction to be addressed was the feed chute that dropped CKD into the tank. Water that splashed up into the chute attracted CKD and began a buildup that would plug the chute within a few days (Figure 5). The chute was shortened to lift it above the water level, sanded and painted inside to prevent CKD from sticking, and was also fitted with a small vibrator to shake the CKD loose.

Figure 5. Partly plugged feed chute.

Figure 6. Photo of leaf rake cleaning the feeder.

CKD also sticks to the rotary vane feeder causing the feed rate to fluctuate wildly when a buildup breaks loose. The vane feeder problem was corrected by placing a leaf rake into the chute to clean the feeder as it rotated (Figure 6).

CKD sticking to the high density polyethylene (HDPE) tank walls built up to the point that a large chunk of mostly solid CKD would break off and plug the drain. This was addressed by installing a motorized float controlled valve and filling the tank, then draining it. This raised the water level causing more trouble with the feed chute. It also caused trouble with the floats, which wore out in a matter of months by mechanical abrasion, causing the tank level to drop. Modifications to the tank to create an adjustable siphon discharge allowed removal of the floats, thus simplifying the system.

The project location at about 11,600 feet elevation made vehicle access after the first of the year increasingly more difficult. Snowshoes were the solution to this issue. The operator snow shoed into the site from the junction of South Mosquito Creek and Mosquito Creek carrying the tools expected to be used that day. The site was visited approximately once every two weeks through the winter. This saved considerable cost in plowing the road.

The above malfunctions were addressed and modified until the system operated as envisioned. Some of the sampling results are presented in the following:

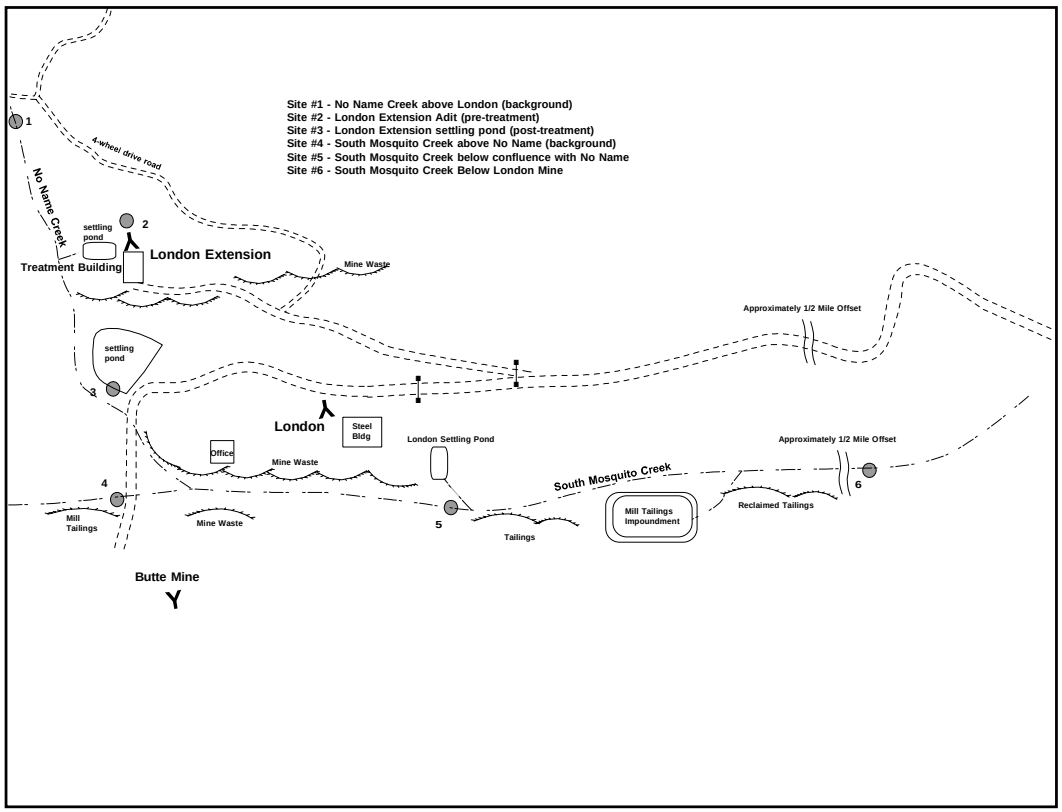

Figure 7. Plan view of London Extension with water sampling locations (not to scale).

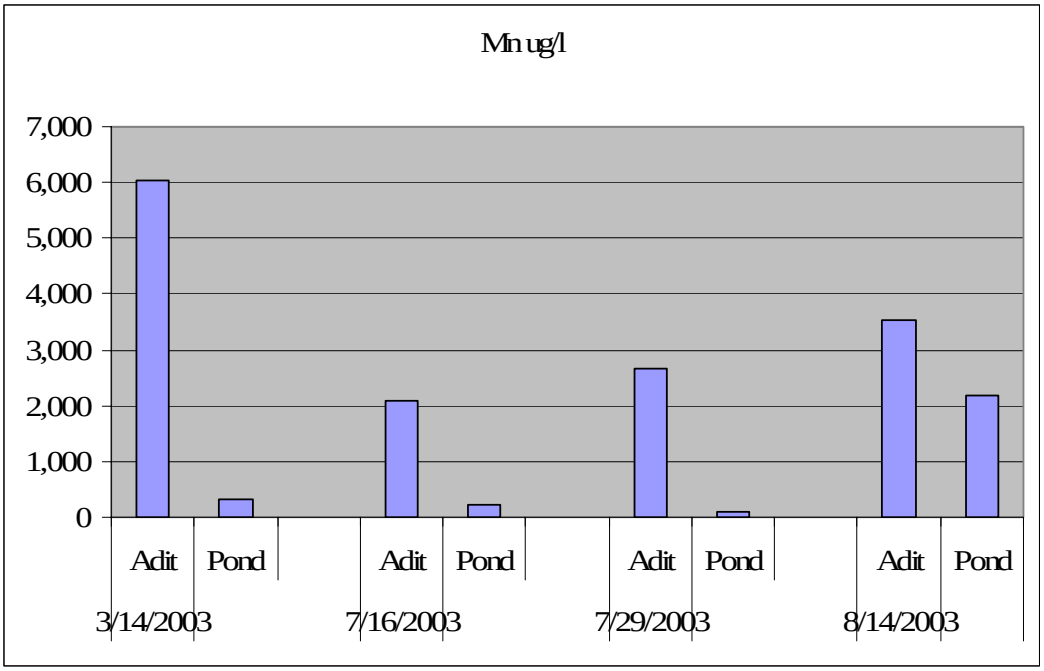

Figure 8. Reduction in Manganese, samples taken before and after CKD treatment.

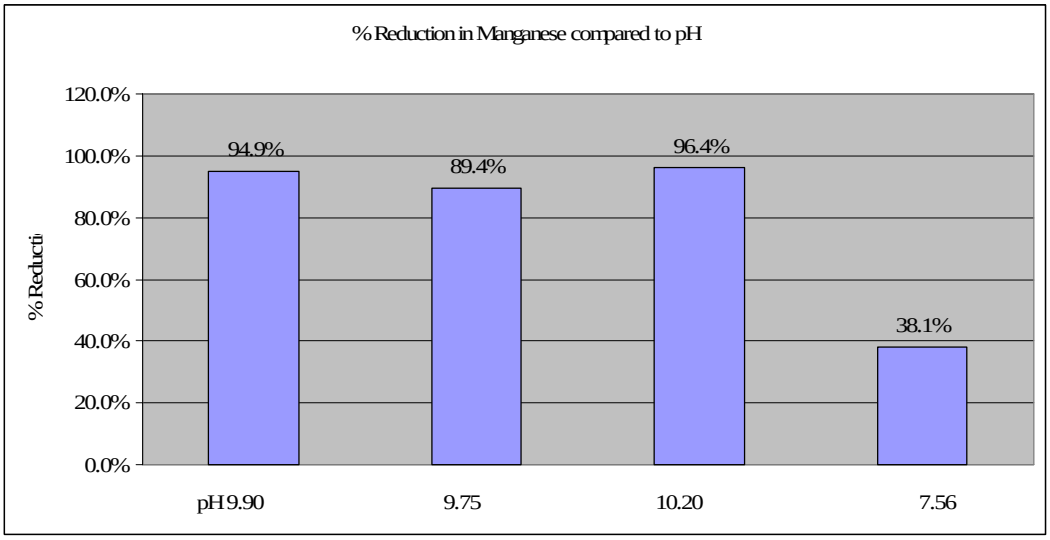

Figure 9. % Reduction in Manganese for the same samples, compared to the treatment pH.

The preceding set of graphs for manganese reduction shows the system's ability to reduce manganese concentration from relatively high values to relatively low values. The variability in the efficiency of the system at different pH levels and at different input concentrations is striking. The best performance is shown on July 29, 2003 when the pH was the highest (10.20) and the concentration of manganese coming into the system was relatively low (2,676). The system removed 96% of the manganese. The last sample taken on August 14, 2003,

shows manganese reduction of only 38% at a pH of 7.56, demonstrating the sensitivity of manganese to treatment pH.

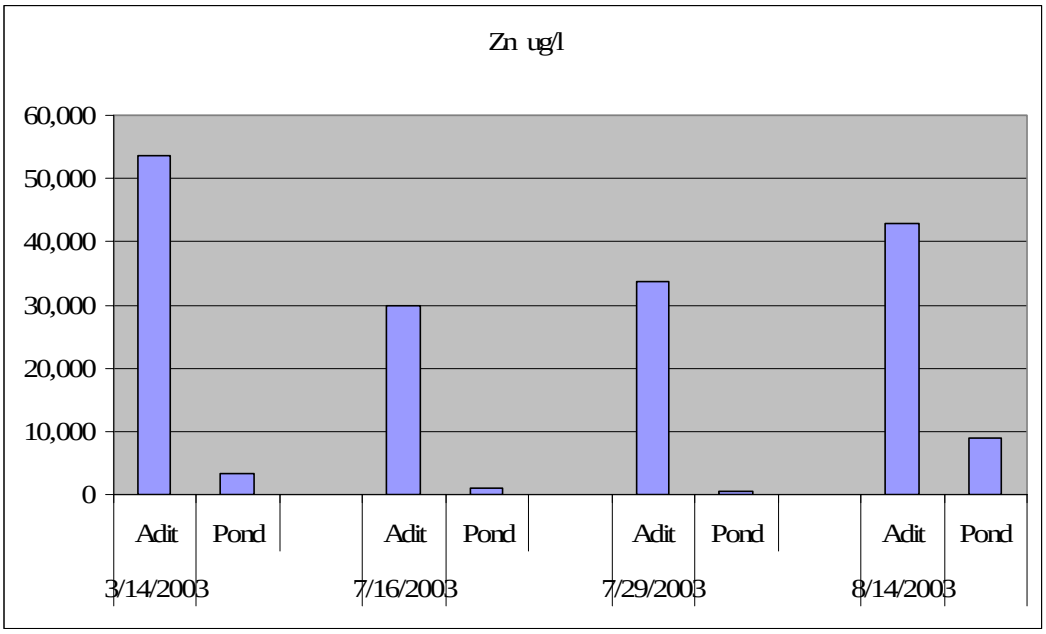

Figure 10. Graph of zinc reduction before and after treatment system.

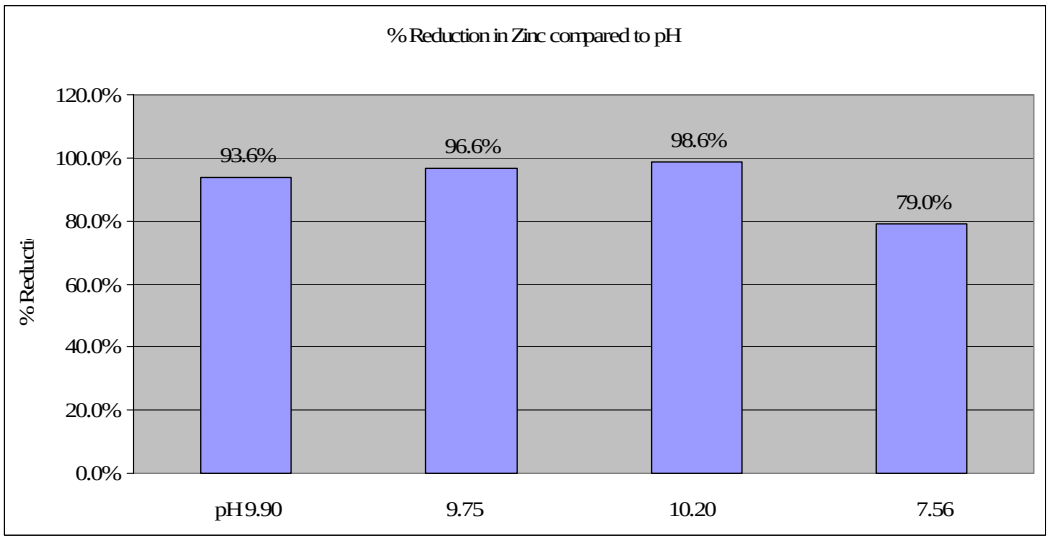

Figure 11. % Reduction in Zinc for the same samples, compared to the treatment pH.

The reduction of Zinc is more uniform in the system. Figure 10 on August 14, 2003, shows an appreciable spike in zinc in the pond sample as a result of the pH dropping below 9.50. On this day, the pH was 7.56 causing the efficiency of the system to drop to 79% removal. This represents nearly 20% reduction in zinc removal efficiency for the approximately 2 pH point drop.

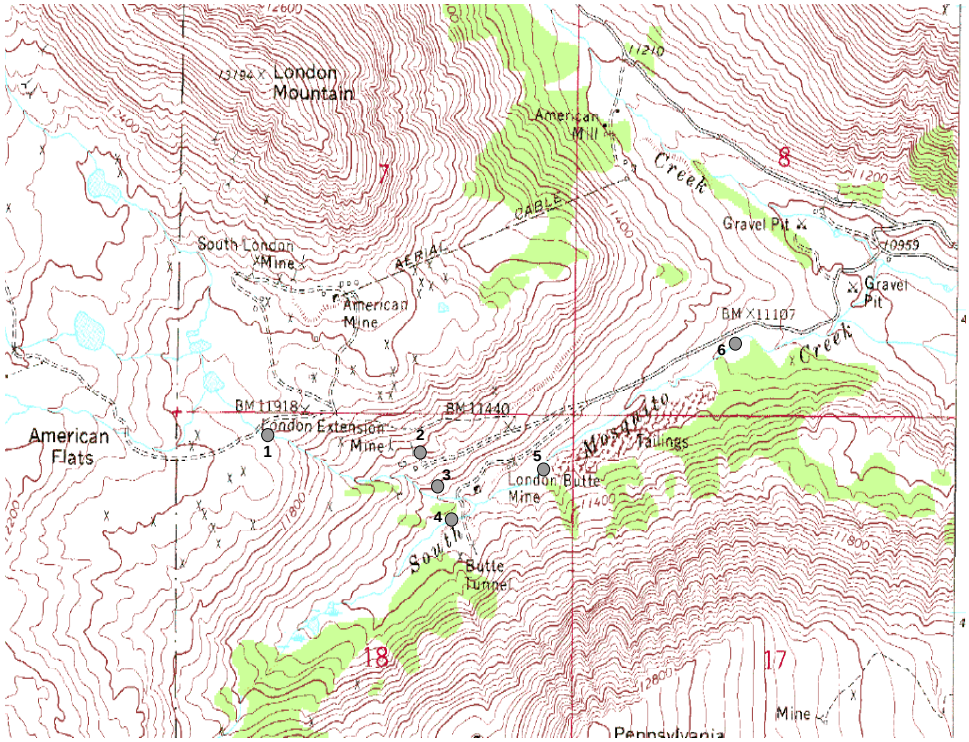

Figure 12. Showing the sampling locations.

Discussion

The graphs shown above for manganese and zinc show an impressive reduction in metal concentration for the first three sampling periods, with a decrease in metal reduction in the sample for August 14, 2003. The following will discuss the relation between metal concentration and pH of the incoming stream and the treatment pH as it effects the metal reduction for the system.

Manganese Reduction: Figure 12, Manganese values showing reduction on March 14, 2003 from 6,026 ug/l to 308 ug/l at treatment pH of 9.90, and reduction on July 16, 2003 from 2,102 ug/l to 223 ug/l at a treatment pH of 9.75, and reduction on July 29, 2003 from 2,676 ug/l to 97 ug/l at treatment pH of 10.2 and reduction on August 14, 2003 from 3,546 ug/l to 2,195 ug/l at treatment pH of 7.56. This represents a reduction of manganese of only 38%, indicating that manganese removal is extremely pH sensitive. We note the highest metal concentration in the input in March, with 6,026 ug/l and a pH of 3.65, raised to pH of 9.90 yielding a reduction of 94.9%.

The reduction of manganese shows the response of the system and individual metals to the pH of the incoming water stream and to the treatment pH.

The sample from August 14, 2003, is less impressive than the rest, but a review of the table below Figure 13 shows that performance of the system at pH 7.56 begins

to drop for Cd and for Mn and for Zn. This demonstrates how important it is to maintain the pH between 9.5 and 10 for optimum performance.

Summary

At the time of writing, the original contractor, Frontier Environmental, is completing several measures to address the lessons learned in the initial operation of the plant as well as re-timbering the area from the portal to the bulkhead, a maintenance issue that can be expected in any abandoned mine. A recent conversation with the contractor indicates that the new and improved plant could be constructed today for a cost in the range of $250,000 to $300,000.

Treatment of mine water at the London Extension mine demonstrates several points: 1) the need for "Good Samaritan" legislation; 2) effective water treatment can be accomplished on a limited budget; and 3) cooperation between state and federal agencies benefits water quality and the aquatic environment.

Good Samaritan legislation has been proposed in several forms, most with the objective of allowing water treatment by agencies, stakeholder groups or water rights owners to treat water much as DRMS did without accepting the liability of removing 100% of the pollutants and operating that treatment plant forever. As the regulations presently exist and are enforced, any entity beginning water treatment must meet the applicable water quality for aquatic life in perpetuity. Construction, operation and maintenance of a complex water treatment plant is beyond the reach of most organizations, and the prospect of perpetual treatment can be terrifying. This demonstration project was delayed several times due to the risk of DRMS being required to accept the permit and operate the plant forever. Good Samaritan legislation would enable interested parties to construct and operate a simple plant and as a result treatment technology would improve.

Construction of a simple water treatment plant for a cost in the range of $250,000 to $300,000 may be within the reach of stakeholder groups or water rights owners. If the annual operation can be kept low enough, (we operated for approximately $10,000 per year) this type of plant may become attractive.

Possibly the most beneficial result of this demonstration is showing that developing a cooperative relationship between all the agencies and institutions involved in an area reaps far-reaching benefits to all concerned and most importantly to the water quality of the state.

Table of Water Sampling Values

Sample Date	Sample Location	Flow cfs	pH ug/l	Al ug/l	Cd ug/l	Fe ug/l	Mn ug/l	Zn ug/l
3/14/2003	Adit **2**	0.025	3.65	3,352	191	61,104	6,026	53,502
3/14/2003	Settling Pond **3**	0.025	9.90	366	11	3,432	308	3,399
% Reduction				**89.1%**	**94.2%**	**94.4%**	**94.9%**	**93.6%**
7/16/2003	Adit **2**	0.24	5.29	1,567	124	35,868	2,102	29,804
7/16/2003	Settling Pond **3**	0.24	9.75	118	4	999	223	1,011
% Reduction				**92.5%**	**96.8%**	**97.2%**	**89.4%**	**96.6%**
7/29/2003	Adit **2**	0.18		2,107	146	41,549	2,676	33,798
7/29/2003	Settling Pond **3**	0.18	10.20	35	2	436	97	461
% Reduction				**98.3%**	**98.6%**	**99.0%**	**96.4%**	**98.6%**
8/14/2003	Adit **2**	0.116	4.49	2,734	173	51,581	3,546	42,880
8/14/2003	Settling Pond **3**	0.116	7.56	72	61	998	2,195	8,993
% Reduction				**97.4%**	**64.7%**	**98.1%**	**38.1%**	**79.0%**

Figure 13. Water sampling results reported in parts per billion ug/l(PPB).