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DEMONSTRATION OF AQUAFIX AND SAPS PASSIVE MINE WATER TREATMENT TECHNOLOGIES AT THE SUMMITVILLE MINE SITE

Innovative Technology Evaluation Report

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
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Abstract

As part of the Superfund Innovative Technology Evaluation (SITE) Program, the U.S. Environmental Protection Agency (EPA) evaluated passive water treatment (PWT) technologies for metals removal from acid mine drainage (AMD) at the Summitville Mine Superfund Site in Southern Colorado.

PWT technologies have been demonstrated to be effective in removing high concentrations of metals (aluminum, copper, iron, manganese, and zinc) from AMD. These systems supply alkalinity to the mine drainage along with aeration to precipitate metals such as aluminum and iron as oxides and hydroxides (oxyhydroxides). The technology is waste-stream specific, requiring characterization of all organic and inorganic constituents. Two technologies were evaluated for this project: the Successive Alkalinity Producing System (SAPS), a PWT technology, and the Aquafix treatment system, which is a semi-passive treatment technology.

In consideration of the severity of the AMD quality at the Summitville site, an iron settling pond pretreatment system was constructed upstream from the SAPS pond. This pond provided a means to aerate the AMD, allowing oxidation and precipitation of ferric ion prior to SAPS treatment. From the Reynolds Adit collection sump, AMD was delivered as influent to the SAPS at a rate of 5 gallons per minute (gpm). This influent was aerated by passage through a spray nozzle to atomize the AMD as it settled into the pond. The iron, and potential co-precipitated metals, settled to the bottom of this pond prior to delivery into the SAPS.

The SAPS consists of a pond that contains three sections or layers: ponded water, compost, and crushed limestone. AMD effluent enters the pond just above the compost layer and flows down through the compost and limestone. Discharge from the SAPS enters a settling pond approximately 2 feet below the pond surface. Discharge from the settling pond was routed to a rock drain or limestone channel for final treatment (polishing).

The Aquafix system consists of a water wheel mechanical distribution system for addition of alkaline material to the AMD; ideally, the treated drainage stream would be delivered to a settling pond. The Reynolds Adit collection sump provided AMD influent for the Aquafix system at a rate of 19 gpm. Due to a lack of sufficient surface area at the site, Baker tanks were used in place of settling ponds. The Aquafix machine provides the addition of lime at a rate proportional to the AMD flow rate. After the lime has been added, the AMD is routed through a rock drain to promote mixing and dissolution of the lime and aeration of the AMD, which causes the metals to precipitate.

The results of the PWT technology evaluation demonstrated that the treatment systems removed the metals from the AMD. Removal efficiencies ranged from 11 percent to 97 percent for the SAPS, and as much as 97 percent to 99 percent for the Aquafix treatment system.

Economic data indicate that the costs for both the SAPS and Aquafix systems is $0.005 per gallon for the 25 gpm systems.

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Acronyms, Abbreviations, and Symbols

°C	Degrees Celsius
°F	Degrees Fahrenheit
%RE	percent removal efficiency
AMD	Acid mine drainage
ARAR	Applicable or relevant and appropriate requirement
CDPHE	Colorado Department of Public Health and Environment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CWA	Clean Water Act
EPA	U.S. Environmental Protection Agency
FS	Feasibility study
gpm	Gallons per minute
HSWA	Hazardous and Solid Waste Amendments of 1984
ITER	Innovative technology evaluation report
LC_{50}	Lethal concentration for 50 percent of the test organisms
mg/kg	Milligrams per kilogram
µg/L	Micrograms per liter
mg/L	Milligrams per liter
MS	Matrix spike
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NOAEL	No observed acute effect level in 48-hour period
NOEC	No observed effect concentration in 7-day period
NPDES	National Pollutant Discharge Elimination System
NRMRL	National Risk Management Research Laboratory
O&M	Operation and maintenance
OSHA	Occupational Safety and Health Administration
PPE	Personal protective equipment
ppm	Parts per million
PVC	Polyvinyl chloride
PWT	Passive water treatment
QAPP	Quality assurance project plan
QA/QC	Quality assurance/quality control
RCRA	Resource Conservation and Recovery Act
RI	Remedial investigation
SAPS	Successive Alkalinity Producing System
SARA	Superfund Amendments and Reauthorization Act
SITE	Superfund Innovative Technology Evaluation
SWDA	Solid Waste Disposal Act
TCLP	Toxicity characteristic leaching procedure
TDS	Total dissolved solids
TOC	Total organic carbon
TSS	Total suspended solids

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Executive Summary

This Innovative Technology Evaluation Report (ITER) documents the results of an evaluation of passive water treatment (PWT) technologies at the Summitville Mine Superfund Site in southern Colorado. The PWT technologies were evaluated from August through October 2000. Two remedial technologies were evaluated under the U.S. Environmental Protection Agency's (EPA) Superfund Innovative Technology Evaluation (SITE) Program for removing h igh concentrations of metals (aluminum, copper, iron, manganese, and zinc) from acid mine drainage (AMD): a successive alkalinity producing system (SAPS), and a lime addition approach known as the Aquafix system. A third treatment technology, an ion exchange system using a mixture of natural zeolites, was also slated for evaluation, but construction delays precluded the collection of data from that system. This executive summary discusses technology applications and system effectiveness, and presents an evaluation of the costs associated with the system and lessons learned during the field demonstration. The two technologies evaluated are discussed in more detail below.

SAPS Technology

The SAPS technology has been developed in the public domain over the past 10 years for remediation of AMD. A SAPS is a pond that contains a combination of limestone and compost overlain by several feet of water. Mine drainage enters at the top of the pond; flows down through the compost, where the drainage gains alkalinity and the oxidation-reduction potential decreases; then flows into the limestone below. Dissolution of the limestone increases the alkalinity of the water, resulting in the precipitation of aluminum, copper, iron, manganese, and zinc. The precipitated metals collect at the base of the SAPS pond and in the subsequent settling pond. Removal of collected precipitate from the ponds is required in order to maintain sufficient conditions for the reaction. The frequency of this maintenance is dependent on the metals loading in the AMD, the size and configuration of the ponds, and the efficiency of the precipitation removal. These conditions are evaluated and optimized in order to limit the need for cleaning out the ponds to an annual or seasonal maintenance or longer. The SAPS is fairly simple and economical to implement and is self operating, which makes it ideally suited for remote sites that have sufficient space for the large ponds needed.

The SAPS was constructed downstream of an iron settling pond where AMD was aerated through a spray nozzle to oxidize the ferrous iron, allowing the ferric iron to precipitate. This settling pond may be necessary for sites where high iron content will generate larger volumes of precipitate that can clog SAPS components if not pretreated. After the pretreatment of the settling pond, AMD fed into the SAPS pond for alkalinity treatment that caused a precipitation of metal ions in the waste stream. Precipitated metals were collected in a subsequent settling pond; discharge from the settling pond was then routed through a polishing channel for final treatment. The total treatment time through the entire treatment system was between 14 and 15 days and about 4 days through the SAPS ponds.

Aquafix Technology

The Aquafix system uses the recognized effectiveness of lime addition to raise the pH of the AMD to precipitate metals. For this evaluation, a rock drain was designed downstream from the treatment unit to promote dissolution of the lime; the effluent from the rock drain was further aerated in a mixing tank, and was subsequently sent to two settling tanks connected in series. The calculated total residence time of the system was about 2 days, but the flow rate in this system tended to fluctuate, thereby affecting residence time.

Objectives of the SAPS and Aquafix Technology Evaluation

The primary objective of the SITE Program's evaluation of the SAPS and Aquafix system was to determine the removal efficiency of each technology for aluminum, copper, iron, manganese, and zinc in the AMD. A summary of these results is presented in Table ES-1. Secondary objectives were to (1) monitor the general characteristics of the AMD as it passed through each system; (2) characterize the sludge from the SAPS and Aquafix settling ponds and estimate the volumes of sludge; (3) monitor the use and degradation of materials in the SAPS; (4) evaluate the effectiveness of the SAPS polishing trenches; (5) measure the change in aquatic toxicity attributable to each treatment system; (6) measure and record flow rates for each technology and estimate mass metals loadings; and (7) estimate capital and operating and maintenance (O&M) costs for each technology.

Technology Applications Analysis

PWT technologies have been demonstrated to be effective in removing high concentrations of metals (aluminum, copper, iron, manganese, and zinc) from AMD. These systems supply alkalinity to the AMD, along with aeration, to precipitate metals such as aluminum and iron as oxides and hydroxides (oxyhydroxides). Aeration may consist of atomization (forcing water under pressure from collection behind the bulkhead through a spray nozzle) or simple movement of the AMD through the treatment system. Aeration promotes elimination of metals co-precipitated with iron, such as arsenic, from the AMD. PWT may also be effective in treating other types of acidic metal-laden waste streams. The technologies are waste-stream specific, requiring characterization of organic and inorganic constituents prior to implementation.
The primary reasons for utilizing a PWT system include remote site location, limited access, and little to or no infrastructure available. These performance factors may or may not be relevant to PWT systems designed to treat organic or inorganic (nonmetal) contamination. PWT systems applicability to waste streams is limited at locations where there is low flow rate or lack of constant flow; variable temperature conditions of the waste stream; and sites with little land area for the treatment pond.

The operating parameters that are designed in the treatment process include the controlled flow rate for alkalinity production, metals reduction, and metals precipitation. A hydraulic residence time of 96 hours was found to work well for these types of alkalinity producing systems, as was determined in the preliminary design study.

Maintaining proper hydraulic residence time is one of the most important factors for the success of a PWT system.

Table ES-1. Summary of Contaminant Removal Efficiency of Total Metals

Metal	SAPS Removal[a] (Percent)*	Aquafix Removal[b] (Percent)*
Aluminum	97	97
Copper	90	99
Iron	64	99
Manganese	11	97
Zinc	57	99

Notes:
[a] The average pH in the waste stream for the SAPS system was 6.3.
[b] The average pH in the waste stream for the Aquafix system was 8.4.
* Bias-corrected estimation method used to determine percent removal efficiencies.

For these systems, a short residence time may not allow metals to oxidize and precipitate from the AMD into the settling pond. This short residence time may result in lower metal removal rates. In chemical precipitation systems, compounds that precipitate slowly may not be removed to the same extent as rapidly precipitating compounds.

Economic Analysis

An economic analysis was conducted to examine 11 cost categories for the PWT technologies. The 11 categories include (1) site preparation; (2) permitting and regulatory requirements; (3) capital equipment and construction; (4) startup; (5) labor; (6) consumables and supplies; (7) utilities; (8) residual and waste shipping and handling; (9) analytical services; (10) maintenance and modifications; and (11) demobilization.

A number of factors affect the estimated costs of treating mine drainage with the PWT technology. These factors generally include AMD flow rate, type and concentration of contaminants, water chemistry, physical site conditions, site location, and treatment goals. In addition, the characteristics of the pond sludge produced by these systems will affect disposal costs since these materials may require treatment for off-site disposal.

Based on the criteria evaluated in the cost analysis, the average estimated cost for a SAPS based on a 15 year system life range from $53,400 for a 5 gallons per minute (gpm) system to $111,300 per year for a 100 gpm system. For the 5 gpm system treatment cost is estimated at $0.02 per gallon of AMD and for the 100 gpm system the cost is estimated at $0.002 per gallon.

The average cost for a permanent Aquafix system designed to treat 25 gpm are expected to be approximately $72,400 per year, based on a 15 year system life. For this 25 gpm system, the treatment cost is estimated at $0.005 per gallon of treated AMD and for the 100 gpm system the cost is estimated at $0.003 per gallon.

Treatment Effectiveness

Based on this demonstration, the following conclusions may be drawn about the effectiveness of the SAPS technology.

- The Summitville Mine Site is in a remote location at a high altitude of 11,500 feet with AMD quality extremely high in metals concentration. Significant percentages of aluminum, copper, iron, manganese and zinc were removed from the AMD in these conditions during the demonstration. The removal efficiency, which ranged from a low of 11 percent to 97 percent, was not sufficient to meet Summitville site project objectives.

- Corresponding toxicity results were also observed for this demonstration. Although toxicity of the AMD was reduced by the SAPS, a sufficient amount of toxicity remained in the post-treatment Summitville water. A 100-times greater reduction in the concentration of metals is needed to remove acute toxicity in the rainbow trout, and a 1,000-times reduction in metals is needed to remove acute toxicity in the freshwater invertebrate. A 50-times reduction in metals is needed to achieve a level of no acute effects in the fathead minnows.

- One or more pretreatment ponds may be required upstream of a SAPS at sites where AMD is of severe quality in order to meet project objectives.

- The SAPS is relatively easy to construct with readily available materials.

The following conclusions may be drawn about the effectiveness of the Aquafix system.

- Significant percentages of aluminum, copper, iron, manganese, and zinc were removed from the AMD. During the demonstration, the metals removal efficiency ranged from 97 percent to 99 percent. This performance was limited to short term performance, due to the severe quality of the AMD and the limitations of the system at the Summitville site to properly aerate and permit settling of precipitate. Limited space at the site for this demonstration prohibited the ability to provide a sufficiently sized rock drain and Baker tanks were substituted for settling ponds.

- Fluctuations of AMD flow rate and temperature can significantly impact treatment system performance.

- Due to poor mixing in the rock drain, the effluent was fed into a mixing tank, where aeration was achieved by means of a sparging nozzle to simulate cascade mixing of the effluent to further enhance dissolution and aeration. After sparging, the effluent was

collected in two Baker tanks, which were used for this demonstration due to limited space at the site for construction of a settling pond, which is more typically employed with this technology. System design to accommodate sufficient mixing and settling time of the effluent is essential for meeting project objectives.

- The Aquafix system is relatively easy to purchase and constructed with readily available materials.

In summary, results from this SITE demonstration of the PWT technologies suggest that these systems are capable of reducing the toxicity of contaminated mine drainage by removing metals such as zinc, cadmium, iron, lead, nickel, and silver. In addition, application of this technology to mine drainage containing high concentrations of iron may require pretreatment to remove the iron. If not removed, the iron could precipitate in the treatment pond and could lead to loss of treatment efficiency.

Lessons Learned

The following items highlight lessons learned during the PWT system demonstration at the Summitville Mine Superfund Site. The list is partitioned among five categories of considerations (or concerns): theory, design, construction, operation and maintenance, and analytical.

Theory

PWT technologies have been demonstrated to be effective in removing high concentrations of metals from AMD. These systems supply alkalinity to the AMD, along with aeration, to precipitate metals such as aluminum and iron as oxides and hydroxides (oxyhydroxides). Sites that possess severe AMD water quality may require additional pretreatment and post-treatment systems to supplement the treatment system performance.

Design

Bench-scale treatability testing is an important first step for evaluating design parameters for application of PWT systems at a specific site. Design variables include: 1) amount and composition of alkaline chemical needed to achieve target pH conditions, 2) the volume and mass of precipitant sludge from settling for various pH conditions and settling times, 3) time required for optimal precipitant flocculation and settling, and 4) evaluation of the metals in solution before and after the addition of lime at target pH values.

A hydraulic residence time of 96 hours (estimated) provided good metal removal in the settling ponds in the beginning of the demonstration. Aeration, mixing, and settling time are critical factors for the success of PWT system removal efficiency.

Construction

Effluent collection pipes (polyvinyl chloride [PVC]) should be larger than 1-inch in diameter to prevent clogging from precipitated material. In addition, the effluent collection structure should include cleaning maintenance to allow precipitated material to be periodically removed without driving the precipitate back into the treatment pond.

Ability to collect and maintain a constant flow rate of AMD influent is critical for optimized PWT system performance.

Operation and Maintenance

PWT systems can require regular inspections to ensure that proper flow of AMD is maintained through the treatment systems. However, properly designed and constructed influent distribution and effluent collection networks may reduce inspection frequency.

Treatment system downtime with PWT systems is not high. Effluent piping networks should be cleaned out periodically (once or twice a year may be appropriate). For the SAPS, the frequency of compost removal and replacement will depend on contaminant loading, metal removal efficiencies, and the desired performance level of the treatment system.

Analytical

Routine (monthly) total metals analysis in conjunction with quarterly dissolved metals analysis were useful in evaluating the performance of the PWT systems. The mine drainage and effluents were sampled and analyzed every 2 days during the demonstration due to the limited time available for collecting such information; however, monthly sampling is adequate to track treatment performance.

Routine aquatic toxicity testing of the mine drainage and PWT effluent also provides useful water quality information. During the SAPS demonstration, these analyses were conducted near the end of the demonstration due to the short evaluation time, but semi-annual analyses could also be used. Demonstration aquatic toxicity testing used three test organisms, fathead minnows *(Pimephalus promelas),* water fleas *(Ceriodaphnia dubia)*, and rainbow trout *(Oncorhynchus mykiss)*; however, other test organisms could also be used.

All aqueous field analyses conducted during the PWT systems demonstration including pH, Eh (effluent), dissolved oxygen (influent), conductivity, and temperature were useful measurements.

1
Introduction

This section provides background information about the Superfund Innovative Technology Evaluation (SITE) program, discusses the purpose of this Innovative Technology Evaluation Report (ITER), and describes the Passive Water Treatment (PWT) technologies. Key contacts for additional information about the SITE program, this technology, and the demonstration site are listed at the end of this section.

Passive water treatment technologies (PWT) are designed to remove or neutralize high concentrations of metals (aluminum, copper, iron, manganese, and zinc) from acid mine drainage (AMD). These systems supply alkalinity to the mine drainage along with aeration to precipitate metals such as aluminum and iron as oxides and hydroxides (oxyhydroxides). Two PWT technologies were evaluated at the Summitville Mine Superfund Site (Summitville) in southern Colorado. A Zeolite system PWT technology was also attempted to be included in this demonstration; however, construction delays during installation of the system resulted in insufficient time to collect data. The evaluation was conducted by the U.S. Environmental Protection Agency's (EPA) SITE Program in cooperation with EPA Region 8 and the Colorado Department of Public Health and Environment (CDPHE).

The technology evaluation occurred from August through October 2000. The project evaluated a successive alkalinity-producing system (SAPS) and a semi-passive lime addition system produced by Aquafix Treatment Systems (Aquafix). The SAPS and Aquafix systems use lime to supply alkalinity to the AMD for neutralization and metals precipitation. This ITER summarizes the results of that evaluation and provides other pertinent technical and cost information for potential users of the technology. For additional information about the technologies, the evaluation site, and the SITE Program, refer to key contacts listed at the end of this section.

1.1 Purpose and Organization of the ITER

The purpose of this ITER is to present information that will assist decision-makers in evaluating the PWT technologies for application to a particular site cleanup. This report provides background information and introduces the PWT technologies (Section 1.0), analyzes the technology's applications (Section 2.0), analyzes the PWT technologies' effectiveness in treating AMD (Section 3.0), provides an economic analysis (Section 4.0), summarizes the technology's status (Section 5.0), and presents a list of references used to prepare the ITER. Data summary tables and plots are provided in Appendix A, and photographs taken during the evaluation are provided in Appendix B.

The ITER provides information on the PWT technologies and includes a comprehensive description of the demonstration and its results. The ITER is intended for use by EPA remedial project managers, EPA on-scene coordinators, contractors, and other decision-makers for implementing specific remedial actions. The ITER is designed to aid decision-makers in evaluating specific technologies for further consideration as an option in a particular cleanup operation. This report represents a critical step in the development and commercialization of a treatment technology. To encourage the general use of demonstration technologies, EPA provides information regarding the applicability of each technology to specific sites and wastes. Therefore, the ITER includes information on cost and site-specific characteristics. It also discusses advantages, disadvantages, and limitations of the technology. Each SITE demonstration evaluates the performance of a technology in treating a specific waste. The waste characteristics at other sites may differ from the characteristics of the treated waste. Therefore, successful field demonstration of a technology at one site does not necessarily ensure that it will be applicable at other sites. Data from the field demonstration may

require extrapolation for estimating the operating ranges in which the technology will perform satisfactorily. Only limited conclusions can be drawn from a single field demonstration.

1.2 Site Description

EPA Region 8 and the CDPHE are responsible for remediating the Summitville site. These parties recognized a need to identify cost-effective methods for AMD remediation to support long-term site remediation objectives, and worked with EPA's National Risk Management Research Laboratory (NRMRL) to construct the evaluation systems and to design the evaluation. The SAPS and Aquafix technologies were evaluated in a SITE Program evaluation at the Summitville site, which was carried out under a cooperative agreement among EPA NRMRL, CDPHE, and EPA Region 8.

The Summitville site is an abandoned gold mine located in the San Juan Mountains of southwestern Colorado. The mine occupies approximately 1,400 acres at an elevation of 11,500 feet on the northeastern flank of South Mountain in Rio Grande County, Colorado (Figure 1). The site is located approximately 25 miles from Del Norte, Colorado. The mine is drained by three streams: Cropsy Creek, Wightman Fork, and an unnamed tributary to Wightman Fork. From its confluence with Cropsy Creek, Wightman Fork flows east approximately four miles and empties into the Alamosa River. The Summitville area has long cold winters and short, cool summers.

A major source of contamination at the Summitville site is AMD from the Reynolds adit. The Reynolds Adit was built as a dewatering tunnel to lower the water table, thereby allowing deeper mining without pumping out water. AMD occurs when sulfide minerals in a mine are exposed to oxygen and water. Although sulfide mineral oxidation is a natural process, the amount of material exposed to oxidizing conditions has increased as a result of excavations into the sulfide-bearing rock. Catalyzation of sulfide oxidation reactions by naturally occurring bacteria, such as *Thiobacillis ferroxidans*, may accompany the process and further accelerate the production of AMD (EPA 1983).

1.3 Passive Water Treatment Technologies

PWT technologies allow naturally occurring chemical and biological reactions that aid in AMD treatment to occur within a controlled environment of the technology system, and not in the receiving water body. Passive treatment conceptually offers many advantages over conventional active treatment systems. The use of energy-consuming treatment processes are virtually eliminated with passive treatment systems. Additional advantages to the passive systems are lower labor requirements, lower energy usage, gravity flow through systems, and the operation and maintenance (O&M) requirements of passive systems are considerably less than active treatment systems. PWT technologies are most beneficial for AMD treatment at remote locations, such as sites that possess difficult terrains or lack utilities, and sites with limited or no winter access.

1.3.1 Technology System Components and Function

The two PWT technologies evaluated consisted of the SAPS technology and a semi-passive lime addition system produced by Aquafix. The SAPS and Aquafix systems use lime to supply alkalinity to the AMD for neutralization and metals precipitation. The SAPS technology incorporates compost and limestone in a down-flow pond. The Aquafix system deposits lime pellets into the AMD stream. A process schematic of the demonstrated technologies at the Summitville site is shown in Figure 2. A valve off of the mine seal at the Reynolds Adit was used to obtain an AMD flow stream from the mine pool collected behind the seal. The AMD flow stream was split to deliver an average flow of 5 gallons per minute (gpm) to the SAPS and 19 gpm to the Aquafix system.

1.3.1.1 SAPS Technology

The SAPS technology has been developed over the past 10 years for remediation of AMD. A SAPS is a pond containing a combination of limestone and compost overlain by several feet of water. Mine drainage enters the top of the pond, flows down through the compost, where the drainage gains alkalinity and the oxidation-reduction potential decreases, then flows into the limestone below. Water serves to prevent direct contact of oxygen with the compost layer to moderate the temperature and to minimize oxygen diffusion. These factors assist in reducing oxygen content and boosting the

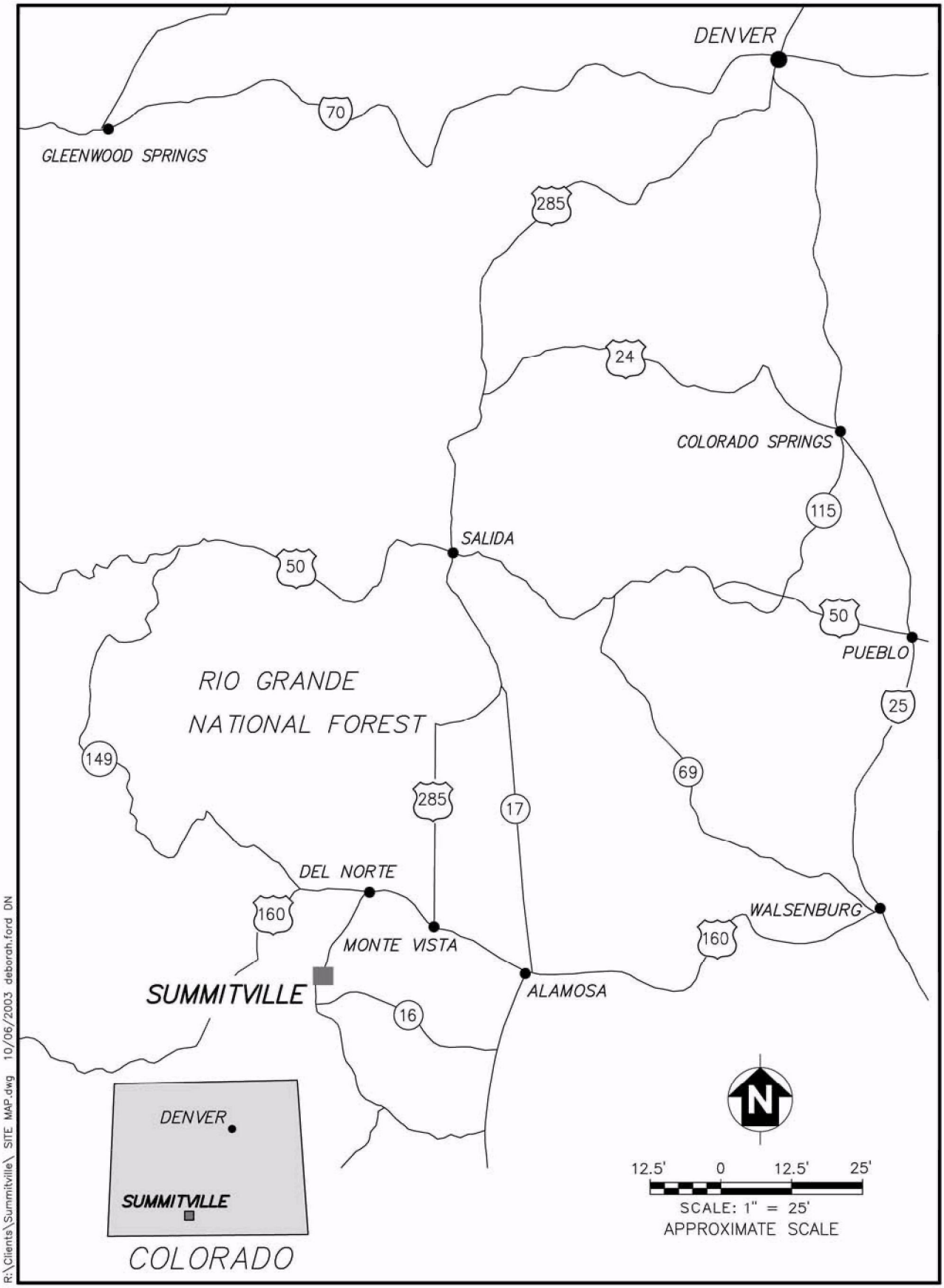

Figure 1. Site Location Map

alkalinity production in the SAPS. Dissolution of the limestone increases the alkalinity in the water, resulting in the precipitation of aluminum and possibly copper. The precipitated metals collect at the base of the SAPS pond or in a subsequent settling pond. These systems are limited by the dissolution rate of the limestone and only remove a portion of the metal contamination from mine drainage. As a result, these systems are often constructed in series to gradually remove the metal contamination.

The treatment components of the SAPS tested at the Reynolds Adit consisted of an iron settling pond preceding a compost/limestone downflow pond, and a final settling pond. Figure 3 shows a flow diagram of the SAPS. The purpose of the iron settling pond was to aerate the mine drainage and oxidize the ferrous iron, allowing the ferric ion to precipitate. The AMD influent gravity controlled flow rate to the iron settling pond was about 5 gpm. The AMD in the iron settling pond had an estimated residence time of about 96 hours. To provide aeration, the influent to the pond was pumped through a spray nozzle into the air and then allowed to rain back into the pond. Pressure from AMD collected behind the bulkhead was used to force water through the spray nozzle in the pretreatment pond. The hydraulic profile of the treatment system is constructed to provide gravity feed of AMD. The hydraulic profile of the SAPS is demonstrated in Figure 4.

The compost/limestone downflow pond, also called the SAPS pond, contained 2.5 feet of ponded water, about 1.5 feet of compost, and 3 feet of 1- to 2-inch-diameter limestone pellets. The SAPS pond was 60-feet long, 40-feet wide, and 7-feet deep. The effluent from the iron settling pond entered the top of the SAPS pond through a polyvinyl chloride (PVC) pipe, valve, or standpipe to control flow. The water flowed down through the compost layer and then through the limestone layer at a flow rate of 5 gpm. The hydraulic residence time of the water within the compost layer was estimated to be 32 hours (assuming a 60 percent water content), and the hydraulic residence time in the limestone layer was estimated to be 32 hours (assuming a 40 percent void volume). The SAPS was constructed using 30 tons of limestone for each gpm of AMD to be treated. The amount of limestone at the Summitville SAPS pond was estimated at 158 tons.

The SAPS settling pond was 52-feet long, 36-feet wide, and 6.5-feet deep. This pond was shaped in a trapezoidal configuration, had a capacity of 36,000 gallons, and the influent residence time was about 5 days. Water flowed across the pond to the primary effluent line, located approximately 6 inches below the top of the pond. Discharge from the SAPS settling pond was routed to either the rock or limestone channels (polishing trenches) for final treatment.

1.3.1.2 Aquafix System

The Aquafix system uses lime to increase the pH of the AMD, in a fashion similar to the SAPS technology. The differences between the two systems are in the method and conditions of lime addition. The Aquafix system, shown in Figure 5, mechanically delivers lime by diverting a portion of the AMD to drive a water wheel. As the water wheel spins it drives an auger suspended above a channel. The auger uses gravity to cause lime pebbles to drop slowly from a hopper into the mine drainage flowing below. The AMD used to drive the water wheel is then returned to the channel. The amount of lime added is proportional to the speed of the water wheel, so the system can be optimized and can even account for moderate changes in AMD flow. Following lime addition, the mine drainage is routed through a rock drain to mix the lime and AMD, and to aerate the AMD. The more alkaline and aerobic conditions of the rock drain cause metals such as aluminum, copper, iron, and zinc to precipitate from solution.

For the Summitville demonstration, the Aquafix system was constructed alongside the SAPS pond. AMD flowing at an average rate of 19 gpm was diverted to the Aquafix lime addition system from a valve in the mine seal at the Reynolds Adit. After lime addition, the AMD flow was channeled down a 200-foot-long slope rock drain to mix the water and lime. The mixing time was estimated to be 5 to 7 minutes for lime to breakdown after coming in contact with water and agitation created by rock drain. The water then flowed into two settling tanks (Baker tanks) connected in series, designed to simulate settling ponds for purposes of the evaluation. A process flow of the Aquafix system is shown in Figure 6.

Based on a preliminary design study completed prior to the Summitville demonstration, a hydraulic residence of 96 hours was determined to be optimum for these types of alkalinity producing systems. However, the total residence time for AMD in the Aquafix system was approximately 2 days. Due to the limited space available on the Summitville site, Baker tanks were used in place of properly sized settling ponds that did not allow for

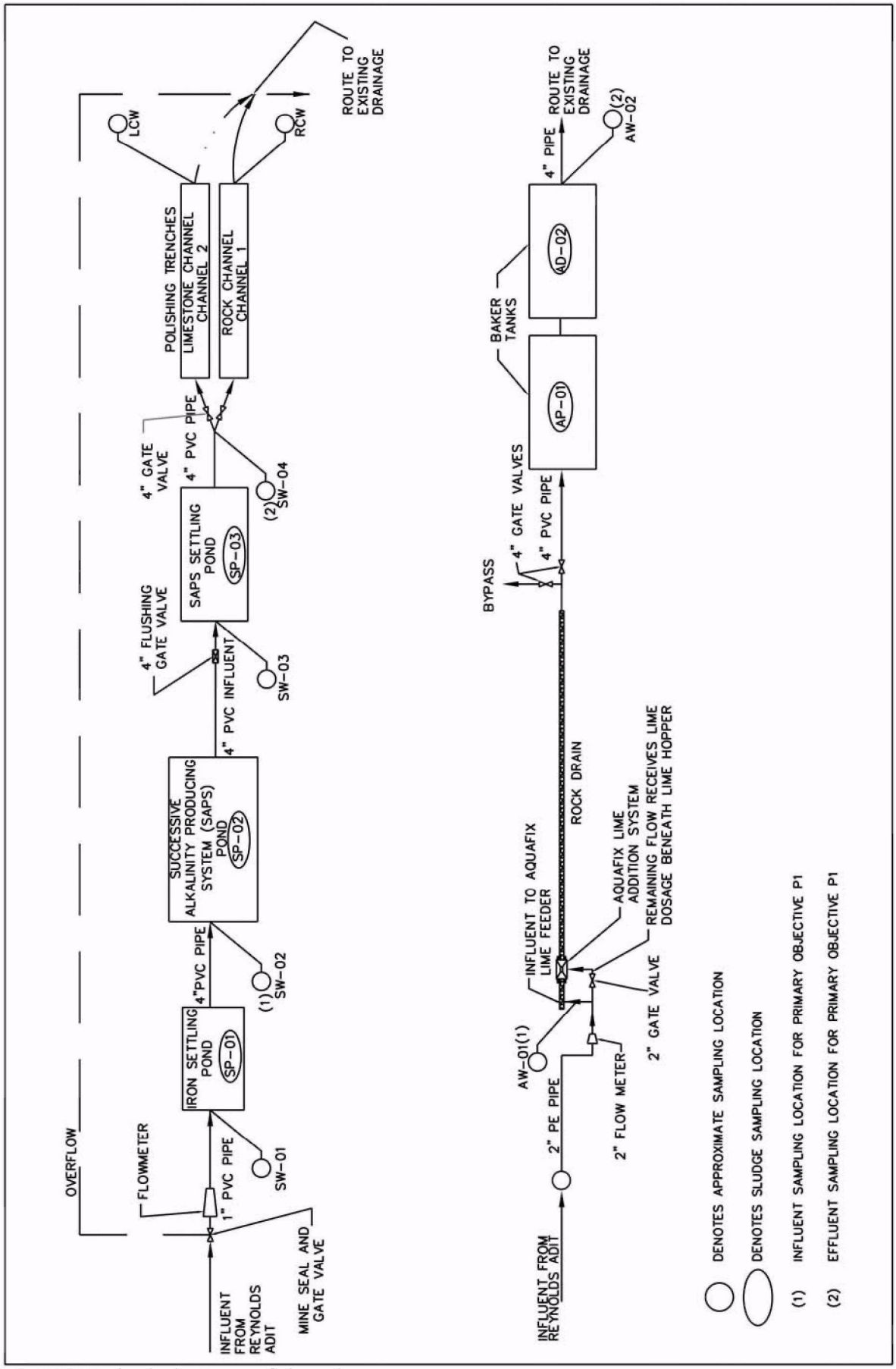

Figure 2. PWT Technologies Process Schematic

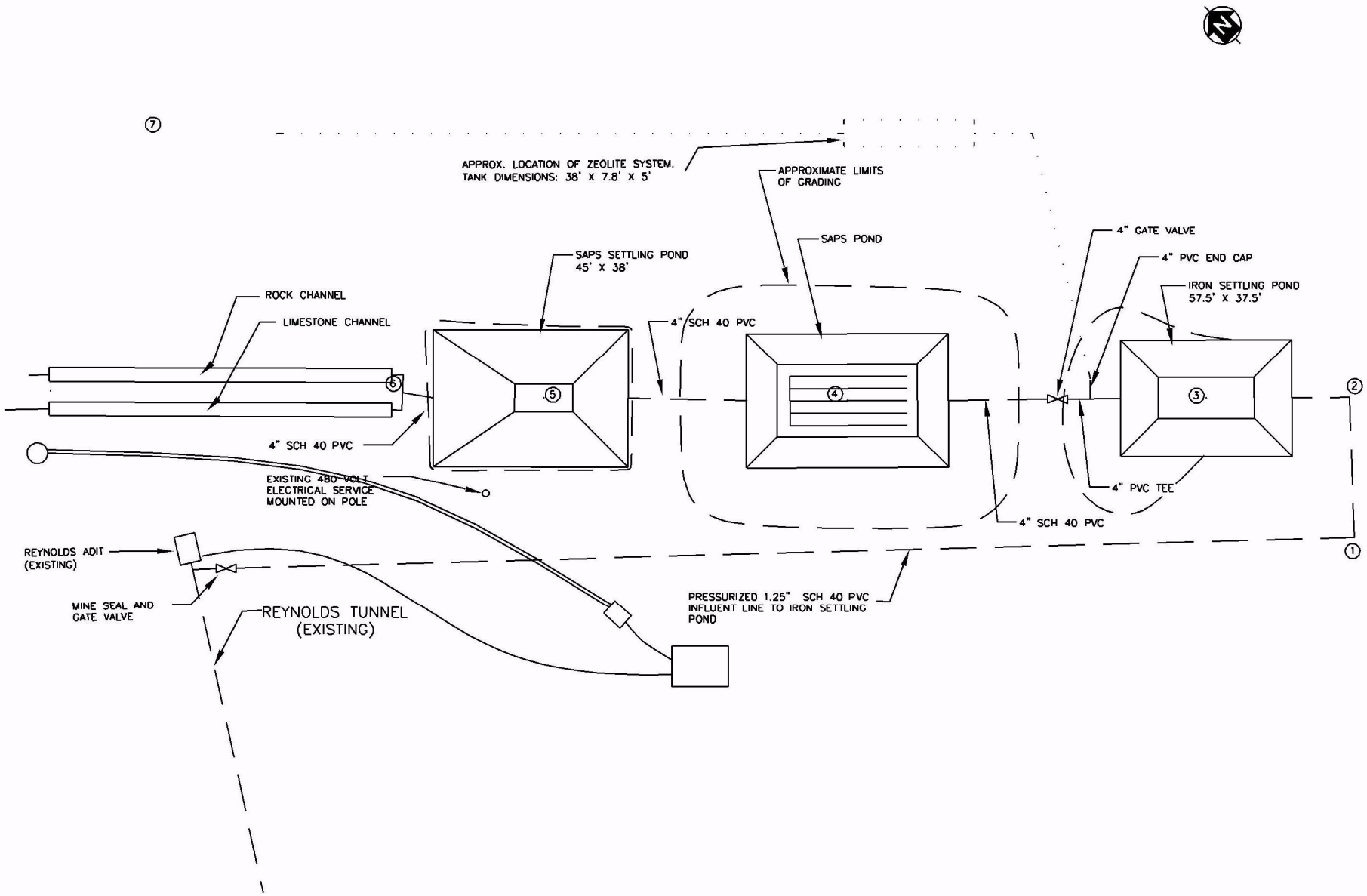

Figure 3. SAPs Flow Diagram

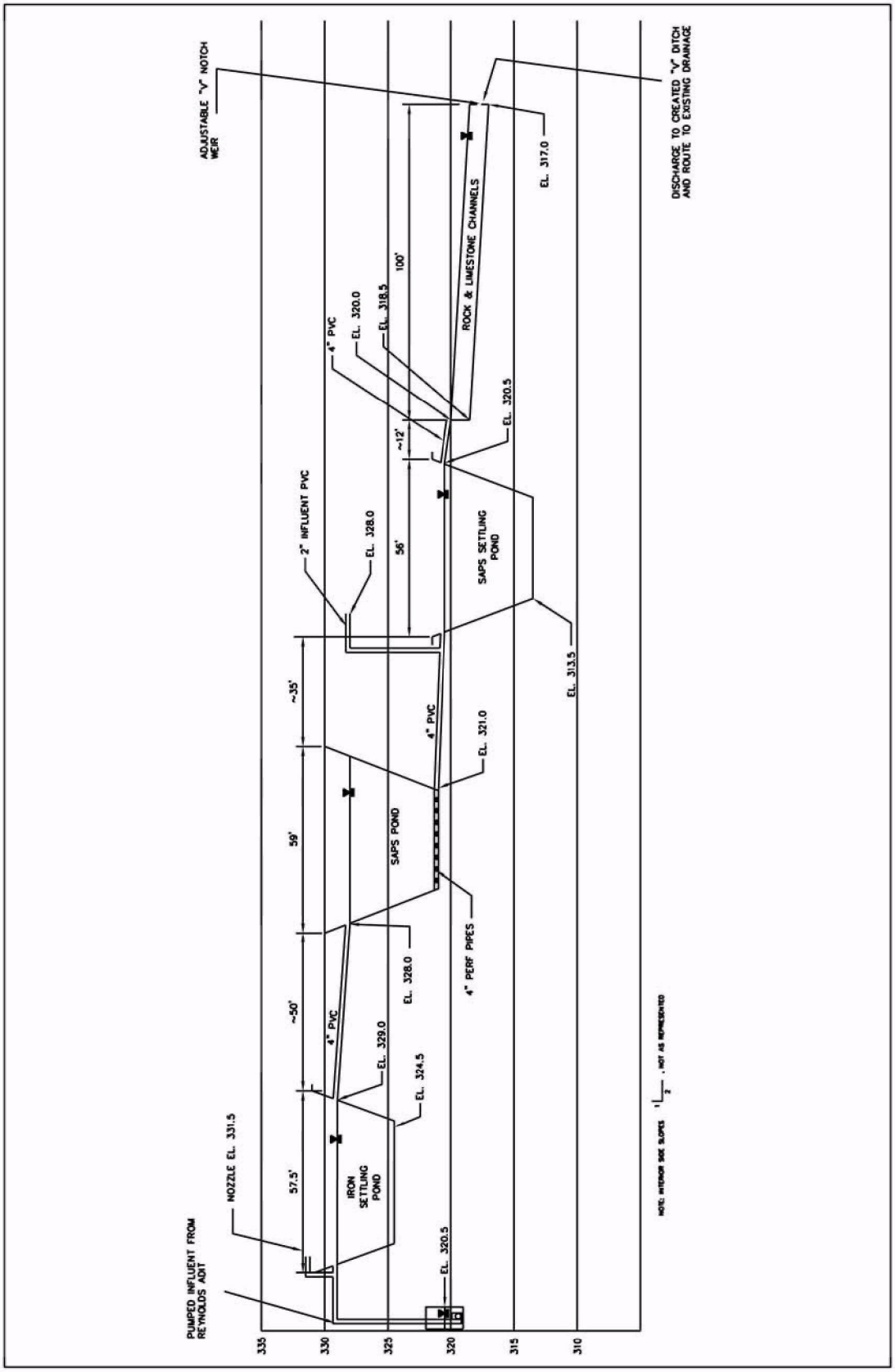

Figure 4. SAPs Hydraulic Profile

sufficient settling time and collection of precipitate. Results of a treatability study conducted by the vendor determined that 0.004143 pound of lime was required to neutralize 1 gallon of AMD. The selected lime pebble size for the evaluation was approximately 0.375 inch in diameter.

1.3.1.3 Zeolite System

For the Summitville demonstration, a single zeolite cell was used. The cell consisted of a 38-foot-long, 7.8-foot-wide, 5-foot-deep tank filled with approximately 29 tons of Z-blend zeolite. AMD flowing at 5 gpm from the iron settling pond was diverted to the zeolite system. The residence time for the AMD in the zeolite cell was approximately 9 hours. The system treated approximately 36,000 gallons of water in a 5–day period. After this time, the zeolite required regeneration.

To regenerate the zeolite, the treated water was first drained from the zeolite cell. A 3 percent sodium chloride solution was pumped from holding tanks into the zeolite cell and allowed to remain in the cell for 8 to 24 hours. The sodium chloride regeneration solution was reused several times, and was eventually pumped to the Summitville impoundment along with effluent from the zeolite system.

The zeolite system was not evaluated as part of this demonstration due to construction delays during installation of the system. No further discussion of this technology or data was available to be included in this report.

1.3.2 Key Features of the PWT Technologies

Technology features can permit an adaptation to a wide variety of settings, as well as limitations to applicability. These features are described in the following sections.

1.3.2.1 SAPS Technology

Certain features of the SAPS technology allow it to be adapted to a variety of settings:

- The hardware components (geosynthetic materials, PVC piping, and flow control units) of the SAPS are readily available.

- Compost substrate materials can be composed of readily available materials; however, the actual composition of a substrate material for a site-specific SAPS is best determined through pilot studies. Spent mushroom compost was used during this demonstration.

- O&M costs are low since the systems are generally self-contained, requiring only periodic changes of substrate materials, and periodic removal of sludge, depending on site-specific conditions.

Other features that should be thoroughly evaluated before constructing a SAPS include the following:

- Chemical properties of the AMD must be evaluated, including pH, metals, total suspended solids (TSS), and anion concentration. Some AMD may need pretreatment before entering the SAPS. For example, AMD with high iron or aluminum content will generate larger volumes of precipitate that can clog the SAPS components if not pretreated to remove some of the metal.

- Climate conditions must be evaluated to assess the potential for reduced efficiency of the system during different seasons of the year, as well as high altitude conditions.

- Proximity to a populated area-odors are generally associated with AMD treatment.

- Land availability near the source of the contaminated water is desirable to avoid extended transport for pond construction. The SAPS typically requires more land than a conventional treatment system. Consequently, locations with steep slopes and drainage would make construction more difficult and costly.

- Cost of constructing the system may increase if substrate and other materials are not readily available.

- Seasonal fluctuation of water flow or chemistry must be evaluated, as well as the potential impact to the SAPS.

1.3.2.2 Aquafix Technology

Certain features of the Aquafix system allow it to be adapted to a variety of settings:

Figure 5. Aquafix Unit

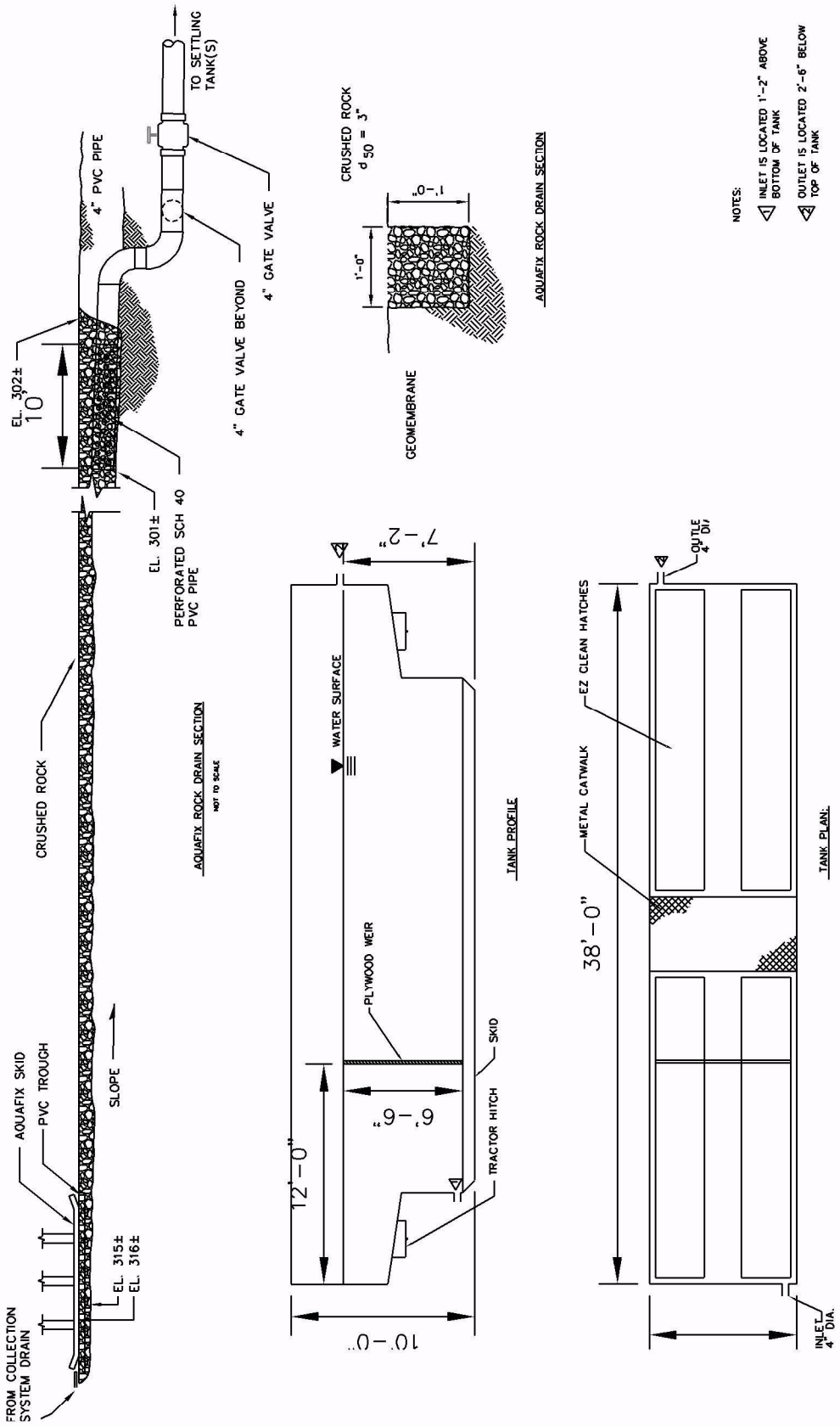

Figure 6. Aquafix Flow Diagram

- The hardware components (geosynthetic materials, PVC piping, and flow control units) for the Aquafix system are readily available.

Other features that should be thoroughly evaluated before implementing the Aquafix system include the following:

- Chemical properties of the AMD must be evaluated, including pH, metals, TSS, and anion concentration. Some AMD sources may need pretreatment upstream from the PWT. For example, drainage with high iron or aluminum content might prematurely clog the equipment and settling pond if not pretreated to remove some of the metal.

- Climate conditions must be evaluated to assess the potential for reduced efficiency of the system during different seasons of the year.

- Land availability near the source of the contaminated water is desirable to avoid extended transport. Land is required for placement of the settling pond; consequently, locations with steep slopes and AMD sources would make construction more difficult and costly.

- Cost of constructing the system may increase if substrate and other materials are not readily available.

- Fluctuation of water flow or chemistry may impact the Aquafix system performance.

- Stream standard conditions should be evaluated for discharge of produced nutrients.

1.4 Key Contacts

Additional information on the PWT technology, the SITE Program, and the Summitville site can be obtained from the following sources:

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2
Technology Applications Analysis

This section of the ITER describes the general applicability of the PWT technologies to contaminated waste sites. The analysis is based primarily on the SITE Program evaluation results. A detailed discussion of the treatability study and evaluation results is presented in Section 3.0 of this report.

2.1 Applicable Wastes and Conditions

PWT technologies have been demonstrated to be effective in removing high concentrations of metals (aluminum, copper, iron, and zinc) from AMD. These systems supply alkalinity to the AMD, along with aeration, to precipitate metals such as aluminum and iron as oxides and hydroxides (oxyhydroxides). Aeration may consist of atomization (forcing pressurized AMD through a spray nozzle) or simple movement of AMD through the treatment system. Aeration promotes elimination of metals co-precipitated with iron, such as arsenic, from the AMD. PWT may also be effective in treating other types of acidic metal-laden waste streams. The technologies are waste-stream specific, requiring characterization of organic and inorganic constituents prior to implementation.

The primary reasons for utilizing a PWT system include remote site location, limited access, and little or no infrastructure available. PWT systems applicability to waste streams is limited at locations with low flow rate or lack of constant flow and temperature conditions of the waste stream, as well as sites with little land area for the treatment pond.

Due to the elevated iron content of the AMD at the Summitville site, an iron settling pond pretreatment system was constructed upstream from the SAPS pond. This pond promoted aeration of the AMD, which in turn promoted the oxidation and precipitation of ferric ion prior to treatment. The influent was aerated by a spray nozzle to atomize the pressurized AMD as it settled into the pond. The iron, and potential co-precipitated metals, such as arsenic present in the AMD settled to the bottom of this pond prior to delivery into the SAPS. Effectiveness of the iron settling pretreatment at the Summitville site was hampered due to the low pH of the influent water.

The results of the PWT technology evaluation (see Section 3.0) demonstrated the ability of the treatment system to remove most metals from the AMD. Removal efficiencies ranged from 11 percent to 97 percent for the SAPS, and from as much as 97 percent to 99 percent for the Aquafix treatment system.

2.2 Factors Affecting Performance

Given the diverse nature of PWT system designs, several parameters affect their operation. The following discussion focuses on the performance factors pertinent to this SITE Program evaluation of the SAPS or Aquafix technologies or to similar systems in treating metal-contaminated mine drainage. Three primary factors influenced the performance of the SITE Program evaluation of the PWT systems: (1) mine drainage characteristics, (2) operating parameters, and (3) aeration of the AMD.

2.2.1 Mine Drainage Characteristics

Four commonly held chemical reactions represent the chemistry of pyrite weathering to form AMD. The first reaction is that of weathering and oxidation through oxygenation of the pyrite. Next, ferrous iron in the drainage is oxidized to form ferric ion. Certain bacteria also increase the rate of oxidation of ferrous iron. The rate of the oxidation reaction proceeds more slowly with increasing acidity (pH) in the drainage. The next reaction that may occur is the hydrolysis of the oxidized metal ions. The final reaction is the oxidation of additional pyrite by ferric ion. Solids form when the pH is in the range of 3.5

or higher, with little or no solids precipitating at pH conditions less than 3.5. The ferric ion generated in the beginning process propagates until either the ferrous iron or the pyrite are depleted. In this propagation reaction, the iron is the oxidizing agent rather than oxygen, which served to initiate pyrite oxidation.

The PWT technologies are capable of treating a range of contaminated waters containing heavy metals. However, the effectiveness of a PWT system can be reduced as solids precipitate and clog the system. Contaminated coal mine drainage sources, considered as a typical application for this technology often contain elevated concentrations of iron or aluminum. When the pH of these solutions is raised during passive treatment, iron and aluminum hydroxides can form and precipitate (Hedin and Others 1994).

The precipitates that are generated during treatment can lead to a loss of permeability or scaling, and gradual filling of the treatment system, which may ultimately lead to system failure. A maintenance schedule that includes removal of precipitate from the treatment system must be implemented to ensure project required system lifetime. Treatment and settling ponds and associated piping are designed and sized to accommodate a specific solids load; therefore, variability in the flow rate of the AMD may also impact treatment efficiency.

2.2.2 Operating Parameters

The operating parameters that are designed in the treatment process include the controlled flow rate for alkalinity production, metals reduction, and metals precipitation. A hydraulic residence time of at least 96 hours was found to work well for these types of alkalinity producing systems, as was determined in the preliminary design study (Tetra Tech 1998). The calculation was based on the volume of the treatment pond system and a flow rate of 5 gpm for the SAPS system and 19 gpm for the Aquafix system.

Maintaining proper hydraulic residence time is one of the most important factors for the success of a PWT system. For these systems, a short residence time may not allow metals to oxidize and precipitate from the AMD into the settling pond. This short residence time may result in lower metal removal rates. In chemical precipitation systems, compounds that precipitate slowly may not be removed to the same extent as rapidly precipitating compounds.

Alkalinity increase in the AMD is adjusted in the design of the treatment system. Alkalinity may be added through placement of limestone in the treatment pond (as in the SAPS), or through addition to the mine drainage as lime, which is the basis for the Aquafix system.

2.2.3 Aeration of the AMD

High concentrations of iron in AMD may require additional treatment for enhanced removal efficiency. For the demonstration at the Summitville site, aeration was utilized with the PWT technologies at various positions within the treatment train. In this aeration process, AMD is infused with air in order to promote the oxidation of aqueous ferrous ion to ferric ion, resulting in precipitation and reduction of the excessive iron loading.

For the SAPS treatment technology, an iron settling pond was used as a pretreatment technique for the iron-laden AMD. Settling pond influent was aerated by passage through a spray nozzle that directed atomized droplets of the water stream into the air. Droplets settled down onto the pond surface, and the resulting precipitate settled to the pond bottom. For this demonstration, the removal efficiency of the iron loading in the AMD through this pretreatment technique was low.

In the Aquafix treatment system, a post treatment aeration tank consisting of a rotary pump and fine bubble diffuser was used for oxidation of the treated AMD stream. In this operation, the aeration system was utilized to enhance the conditions to facilitate the oxidation of ferrous ion to ferric ion, rather than as a source for the oxidation. In this case, aeration enhanced the conditions for the formation of metal hydroxide precipitate.

2.3 Site Characteristics

Site characteristics are important when considering PWT system technology because they can affect system application. Site characteristics should be considered before selecting any technology to treat AMD at a specific site. Site-specific factors include support systems, site area and preparation, site access, climate, hydrology, utilities, and the availability of services and supplies.

2.3.1 Support Systems

If on-site facilities are not already available, a small storage building equipped with electricity may be desirable near the treatment system. The on-site building could be used for storing operating and sampling equipment (tools, field instrumentation, and health and safety gear) and providing shelter for sampling personnel during inclement weather. Sampling personnel also may use the building when needing to calibrate field equipment for system monitoring.

2.3.2 Site Area, Access, and Preparation

PWT systems typically require a relatively larger level area compared with other treatment systems. The size of the treatment and settling pond, site location, grading, and leveling may become cost prohibitive.

Piping or other mechanisms for conveying mine drainage to the treatment system is also necessary. In addition, a relatively constant rate of flow is desirable to maintain treatment system effectiveness. Thus, site conditions may require mine drainage collection, storage, and distribution structures. Piping is also required for movement of flow through the system and for bypass flow around the treatment systems. This bypass piping or conveyance should be oversized to manage 200 percent of the predicted maximum mine drainage discharge.

Access roads for heavy equipment (excavation and hauling) are required for installation and O&M of a PWT system.

2.3.3 Climate

The climate at potential PWT system sites can be a limiting factor. Extended periods of severe cold, extreme hot and arid conditions, and frequent severe storms or flooding will affect system performance. Extreme cold can freeze portions of the PWT system, resulting in channeling of the mine drainage through the substrate, which reduces the hydraulic residence time. In addition, cold temperatures may reduce microbial activity or populations. Reductions in hydraulic residence time and microbial activity will reduce the ability of the PWT systems to remove metals and may require it to be oversized.

Constructing PWT systems in areas with frequent flooding or severe storms can lead to hydraulic overloading or washout of substrate materials. The engineering controls required to overcome these climatic or geographic limitations may eliminate the low cost and low maintenance advantages that make SAPS appealing.

2.3.4 Utilities

PWT treatment systems do not require the use of utilities to operate the system. Any need for electricity will typically require a passive generator or other energy source, since PWT systems are most often applicable for remote locations. In remote areas, an on-site storage building should be provided if possible. A satellite telephone may be required for maintenance and sampling personnel to contact emergency services if needed and for routine communications.

2.3.5 Services and Supplies

The main services required by PWT treatment systems are periodic adjustment of system flow rates, cleaning of effluent pipes, and removal and replacement of substrate materials. Due to the limited time available for testing the PWT system during the SITE Program evaluation, flow rate adjustments and effluent pipe cleaning were not required after the start-up of operations, although they are required for extended operations. Both PWT systems in the evaluation were operated from a collection valve on the seal at the Reynolds Adit, which delivered AMD by pipe to each treatment system. The time between change out of the substrate materials depends on the chemical constituents of the influent water, the configuration and capacity of the treatment pond, and the preferred method of disposal. The substrate lifetime, estimated from nutrient loss and the development of armoring during this evaluation, is estimated to be 2 to 3 years.

2.4 Availability, Adaptability, and Transportability of Equipment

The components of the PWT systems, except for the Aquafix distribution equipment, are generally available locally. The components include standard construction materials for the treatment and settling ponds, liner materials available from several sources, and compost materials, the types of which will depend on the contaminants in the mine drainage. The most suitable compost for a given application can be identified during a treatability study using materials that are available locally.

2.5 Material Handling Requirements

The PWT systems generate spent substrate and settling pond precipitate. These materials will require testing to evaluate disposal options. Depending on the disposal option, dewatering or other pretreatment may be necessary prior to shipment for off-site disposal. Depending on regulatory requirements, the effluent water generated during dewatering may also require additional treatment prior to discharge.

Some PWT compost materials may contain high levels of water-soluble nitrogen or phosphorus compounds. These compounds can be readily leached from the fresh compost during startup of the PWT system. Thus, the PWT system at startup may require treatment to reduce or remove excess nitrogen or phosphorous. Treatment may include land application, if permitted, or effluent collection for subsequent recycling through the PWT system.

2.6 Personnel Requirements

Construction of treatment cells and substrate replacement require heavy equipment operators, laborers, and a construction supervisor. After the treatment and settling ponds are installed, personnel requirements include a sampling team and personnel to adjust system flow rates. Sampling personnel should be able to collect water and substrate samples for laboratory analysis and measure field parameters using standard instrumentation.

All personnel should have completed an Occupational Safety and Health Administration (OSHA) initial 40-hour health and safety training course with annual 8-hour refresher courses, if applicable, before constructing, sampling, replacing compost, or removing a PWT at hazardous waste sites. They should also participate in a medical monitoring program as specified under OSHA requirements.

2.7 Potential Community Exposures

Fencing and signs should be installed around a PWT system to restrict access to the system for both humans and wildlife. The potential routes of exposure include the mine drainage or waste stream, the compost material, and the PWT system effluent. The actual exposure risk depends on the constituents of the specific waste being treated and the effectiveness of the treatment.

The PWT system may also generate low concentrations of hydrogen sulfide gas, depending on the time of year and the biological activity of the SAPS treatment pond. Odors caused by hydrogen sulfide and volatile fatty acids from the decaying compost material may be a nuisance to a local community.

2.8 Evaluation of Technology Against Remedial Investigation/Feasibility Study Criteria

EPA has developed nine evaluation criteria to fulfill the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as well as additional technical and policy considerations that have proven important for selecting potential remedial alternatives. These criteria serve as the basis for conducting bench-scale testing during the remedial investigation (RI) at a hazardous waste site, for conducting the detailed analysis during the feasibility study (FS), and for subsequently selecting an appropriate remedial action. The features of each SITE technology are evaluated against the nine criteria considered as potential remedial alternatives.

The following are the nine evaluation criteria:

- Overall protection of human health and the environment
- Compliance with applicable or relevant and appropriate requirements (ARAR)
- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, or volume
- Short-term effectiveness
- Capability for implementation
- Cost
- State acceptance
- Community acceptance

Table 1 presents the results of this evaluation for the PWT systems. The evaluation results indicate the PWT systems are capable of providing short-term protection of the environment; can reduce contaminant mobility, toxicity, and volume; are cost-effective; are readily

implemented; and provide an acceptable remedy to the community and state regulators. However, the evaluation testing was insufficient to demonstrate long-term effectiveness. The Summitville site was associated with extremely poor water quality, limited area available for installation of a settling pond and more sufficient ditch line for the Aquafix system, and limited time available for testing.

The average metals removal efficiency was in the range of 80 percent for the SAPS. The Aquafix system removal efficiency was in the range of 97 percent. The Aquafix system was shut down early due to clogging in the system by the reacted metal precipitate from the AMD.

2.9 Potential Regulatory Requirements

This section discusses specific environmental regulations pertinent to operation of a PWT, including the transport, treatment, storage, and disposal of wastes and treatment residuals, and analyzes these regulations in view of the evaluation results. State and local regulatory requirements, which may be more stringent, must also be addressed by remedial managers.

ARARs include the following: (1) CERCLA; (2) the Resource Conservation and Recovery Act (RCRA); (3) the Clean Water Act (CWA); and (4) OSHA regulations. These four general ARARs are discussed below; specific ARARs must be identified by remedial managers for each site.

2.9.1 Comprehensive Environmental Response, Compensation, and Liability Act

CERCLA, as amended by the Superfund Amendments and Reauthorization Act (SARA), authorizes the federal government to respond to releases or potential releases of any hazardous substance into the environment, as well as to releases of pollutants or contaminants that may present an imminent or significant danger to public health and welfare or the environment.

As part of the requirements of CERCLA, EPA has prepared the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) for hazardous substance response. The NCP, codified at Title 40 of the Code of Federal Regulation (CFR) Part 300, delineates methods and criteria used to determine the appropriate extent of removal and cleanup for hazardous waste contamination.

In general, two types of responses are possible under CERCLA: removal actions and remedial actions. The PWT technology is likely to be part of a CERCLA remedial action. Remedial actions are governed by CERCLA as amended by SARA. As stated above, these amendments promote remedies that permanently reduce the volume, toxicity, and mobility of hazardous substances, pollutants, or contaminants.

On-site remedial actions must comply with federal and state ARARs. ARARs are identified on a site-by-site basis and may be waived under six conditions: (1) the action is an interim measure, and an ARAR will be met at completion; (2) compliance with an ARAR would pose a greater risk to human health and the environment than noncompliance; (3) it is technically impracticable to meet an ARAR; (4) the standard of performance of an ARAR can be met by an equivalent method; (5) a state ARAR has not been consistently applied elsewhere; and (6) ARAR compliance would not provide a balance between the protection achieved at a particular site and demands on the Superfund for other sites. These waiver options apply only to Superfund actions taken on site, and justification for the waiver must be clearly demonstrated.

2.9.2 Resource Conservation and Recovery Act

RCRA, an amendment to the Solid Waste Disposal Act (SWDA), was enacted in 1976 to address the problem of safe disposal of the enormous volume of municipal and industrial solid waste generated annually. RCRA specifically addressed the identification and management of hazardous wastes. The Hazardous and Solid Waste Amendments of 1984 (HSWA) greatly expanded the scope and requirements of RCRA.

The presence of RCRA-defined hazardous waste determines whether RCRA regulations apply to the PWT technology. RCRA regulations define and regulate hazardous waste transport, treatment, storage, and disposal. Wastes defined as hazardous under RCRA include characteristic and listed wastes. Criteria for identifying characteristic hazardous wastes are included in 40 CFR Part 261 Subpart C. Listed wastes from nonspecific and specific industrial sources, off-specification products, spill cleanups, and other industrial sources are itemized in 40 CFR Part 261, Subpart D.

The PWT system evaluation treated AMD from the Reynolds Adit of the Summitville site. The manure compost was tested regularly to determine whether it

Table 1
Evaluation of Passive Water Treatment Technologies Versus Remedial Investigation/Feasibility Study Criteria

Criterion	Discussion
1. Overall Protection of Human Health	The PWT technologies reduced total concentrations of contaminants in the waste streams, indicating that the technologies may be protective by reducing overall risk. However, results with regard to specific criteria for each technology were variable.
2. Compliance with Applicable or Relevant and Appropriate Requirements	The PWT reduced target parameter concentrations in the AMD; however, did not achieve CDPHE standards. PWT system effluent discharge may require compliance with CWA regulations. The PWT technologies remove contamination from mine drainage, but may not meet low-level discharge requirements. However, use of PWT with other technologies may be effective in meeting low-level discharge requirements.
3. Long-Term Effectiveness and Permanence	The PWT technologies remove contaminants from AMD and therefore is permanent. Long-term effectiveness is dependent on ongoing maintenance and was not evaluated in this demonstration time frame.
4. Short-term Effectiveness	Implementation of this technology presents few short-term risks to community or wildlife.
5. Reduction of Toxicity, Mobility, or volume of Contaminates Through Treatment	PWT reduces contaminant mobility, toxicity, and volume, demonstrated in the short term.
6. Implementability	PWT is readily implemented given appropriate site conditions.
7. Cost	Construction cost of the 5-gpm SAPS is estimated to be $221,700. Operating cost of this system is estimated at $38,660 per year. Construction cost of the 18-gpm Aquafix System is estimated to be $393,000. Operation cost of this system is estimated at $38,030 per year.
8. Community Acceptance	The public usually views the technology as a natural approach to treatment; therefore, the public generally accepts this technology.
9. State Acceptance	The CDPHE found that the technology shows promise for treating acid mine drainage. Based on constraints at the Summitville site, including the high altitude, cold climate and remote location, CDPHE recommended not implementing a full-scale, permanent system at the site. Colorado's Division of Minerals and Geology has previously built a PWT system to treat acid mine drainage.

would become a hazardous waste during the evaluation. The concern was that sorption and precipitation of metals could cause the substrate to become a hazardous waste, thus restricting options and increasing cost for material disposal. The substrate did not exhibit the characteristics of hazardous waste at the end of the demonstration.

2.9.3 Clean Water Act

The objective of the CWA is to restore and maintain the chemical, physical, and biological integrity of the nation's waters. To achieve this objective, effluent limitations of toxic pollutants from point sources were established. Wastewater discharges are most commonly controlled through effluent standards and discharge permits administered through the National Pollutant Discharge Elimination System (NPDES) by individual states with input from the federal EPA. Under this system, discharge permits are issued with limits on the quantity and quality of effluents. These limits are based on a case-by-case evaluation of potential environmental impacts and on waste loading allocation studies aimed at distributing discharge allowances fairly. Discharge permits are designed as an enforcement tool with the ultimate goal of achieving ambient water quality standards.

NPDES permit requirements must be evaluated for each PWT system when the effluent water is discharged into a waterway or water body. The requirements and standards that must be met in the effluent for each PWT will be based on the waterway or water body into which the PWT discharges. The effluent limits will be established through the NPDES permitting process by the state in which the PWT is constructed and by EPA.

CDPHE has identified water quality standards for Reynolds Adit of Summitville mine discharge into the Alamosa River. Table 2 provides these standards for both low- and high-flow conditions. The zinc standard for both low- and high-flow conditions is 200 micrograms per liter (μg/L) in the river. To meet this standard, the discharge from Reynolds Adit must contain less than 13,650 μg/L zinc under low-flow conditions and less than 65,700 μg/L under high-flow conditions.

2.9.4 Occupational Safety and Health Act

CERCLA remedial actions and RCRA corrective actions must be conducted in accordance with OSHA requirements detailed in 29 CFR Parts 1900 through 1926, especially Part 1910.120, which provides for health and safety of workers at hazardous waste sites. On-site construction at Superfund or RCRA corrective action sites must be conducted in accordance with 29 CFR Part 1926, which provides safety and health regulations for construction sites. State OSHA requirements, which may be significantly stricter than federal standards, must also be met.

Construction and maintenance personnel and sampling teams for the Summitville PWT system evaluation all met the OSHA requirements for hazardous waste sites. For most sites, the minimum personal protective equipment (PPE) required would include gloves, hard hats (during construction), steel-toed boots, and eye protection. Additional PPE may be required during summer or winter months to protect against extreme temperatures.

2.10 Limitations of the Technology

Land required for PWT systems is typically extensive compared to conventional treatment systems. As a result, a PWT system may be inappropriate in areas with high land values. Land availability relatively close to the source of contaminated water is preferred to avoid extended transport.

The climate at potential PWT sites can also be a limiting factor. Extended periods of severe cold, extreme heat, arid conditions, and frequent severe storms or flooding can result in performance problems. Contaminant levels in treated and discharged water can vary in response to variations of influent volumes, temperature, and chemistry. These levels may also be a limiting factor if there is no tolerance in contaminant level discharge requirements.

Table 2

Summary of Analytical Results for Untreated Reynolds Adit Mine Drainage Summitville Site, Colorado

Analyte	Average Concentration[a] (µg/L)	Colorado Department of Public Health and Environment Water Quality Standards (µg/L)
Aluminum	241,000	--
Arsenic	2,100	150 (low and high flow)
Calcium	168,000	0.49 (low flow) - 0.84 (high flow)
Copper	113,000	4.7 (low flow) - 8.5 (high flow)
Iron	669,000	1,000 (low and high flow)
Mercury	0.044	0.84 (low flow) - 2.25 (high flow)
Magnesium	63,000	--
Manganese	33,000	1,000 (low and high flow)
Potassium	3,800	--
Sodium	16,000	--
Zinc	32,000	200 (low and high flow)
Sulfate	3,340	--
Chloride	3.6	--
Total Suspended Solids	15.2	--
Dissolved Oxygen	14.9	--
pH	3.0 pH units	6.5 (low flow) - 8.5 (high flow)
Conductivity	4159 µS/cm	--
Temperature	5.8 °C	--

Notes:

[a] Average concentrations for analytes listed in table are based on data collected during a preliminary design study conducted in October 1997, prior to the Summitville evaluation.

µg/L Micrograms per liter

– No standard established

µS/cm Micro siemens per centimeter

3
Treatment Effectivemess

The following sections discuss the treatment effectiveness of the PWT systems based on the demonstration at the Summitville site. The discussion includes a review of the evaluation methodology, site evaluation results, and evaluation conclusions.

3.1 Background

The Summitville site is an abandoned gold mine that occupies approximately 1,400 acres on the northeast flank of South Mountain in Rio Grande County, Colorado (Figure 1). n Fork flows east for approximately 4 miles and empties into the Alamosa River. The site is bounded by the town of Summitville and Wightman Fork on the north, Cropsy Creek on the east, and the summit of South Mountain on the southwest (Tetra Tech 1998).

A major contamination source at the Summitville site is AMD from the Reynolds tunnel. This tunnel or "adit" was constructed in 1897. It was built as a dewatering tunnel to lower the water table and allow deeper mining without pumping out water. AMD occurs when sulfide materials in the mine are exposed to water and oxygen. Although sulfide mineral oxidation is a natural process, the amount of material exposed to oxidation has increased as a result of mining activity in the sulfide-bearing rock. Catalyzation of sulfide oxidation reactions by naturally occurring bacteria, such as *Thiobacillis ferroxidans*, may accompany the process and further accelerate the production of AMD (EPA 1983).

Although historic releases from this tunnel have always had high metal concentrations, the level of metal concentrations in the effluent dramatically increased starting in 1988. It appears that excavation of an open pit approximately 300 feet above the Reynolds tunnel stimulated increased infiltration and oxidation of the ore body, resulting in increased release of acid and metals contamination to the Reynolds tunnel (Tetra Tech 1998).

The Summitville Mine area has long, cold winters and short, cool summers. Winter snowfall is normally heavy and thunderstorms are common in the summer. The site is very rugged and access to the site is limited in the winter, since one road is maintained to the site during the winter season.

3.2 Review of SITE Evaluation

The SITE evaluation was divided into three phases: (1) PWT preliminary design and treatability study; (2) PWT technology evaluation; and (3) site demobilization. These activities are discussed in the following sections, which also discuss variations from the work plan and the PWT performance during the technology evaluation phase.

3.2.1 PWT Preliminary Design and Treatability Study

Bench-scale testing was conducted at the Colorado School of Mines to evaluate the effectiveness of the PWT technologies to remove metals from the AMD at the Summitville site. The bench-scale testing was performed to evaluate design variables for application of the PWT system to the Summitville site conditions. These variables included (1) amount and composition of alkaline chemical needed to achieve the target pH of treated water, (2) the volume and mass of precipitant sludge from settling for various pH conditions and settling times, (3) time required for optimal precipitant flocculation and settling, and (4) evaluation of the metals in solution before and after the addition of lime at each of the target pH values.

Jar testing was conducted for neutralizing AMD to the following pH values: 6.5, 7.5, 8.5, and 9.5. From the results at these test conditions, the optimum design criteria were determined for implementing PWT at the Summitville site.

A treatability study for the Aquafix system was conducted by the vendor. This study determined the amount of lime needed per gallon of water treated as well as the selected lime pebble size for the site-specific application.

3.2.2 Technology Evaluation

The treatment systems were constructed adjacent to each other at the Summitville site in the spring and summer months in 2000; data collection commenced in August 2000.

Site preparation requirements for the PWT system evaluations were minimal because of previous mining and treatability study activities. Moreover, the area east of the Reynolds Adit is level and required only minor grading to install the settling and treatment ponds for both the SAPS and Aquafix systems. Construction and installation of the PWT systems and all drainage conveyances was the responsibility of the state (CDPHE).

Throughout the evaluation, mine drainage influent and treatment pond effluent samples were collected for analysis of total metals, anions, TSS, and total organic carbon (TOC). In addition, pond sludge samples were collected during the evaluation for analysis of total metals and toxicity characteristic leaching procedure (TCLP) metals.

3.2.3 Operational and Sampling Problems and Variations from the Work Plan

The PWT experienced several operational problems during the technology evaluation. Some of these problems resulted in changes to the schedule and sampling events. Problems encountered and resolutions effected during the evaluation are described below.

The major drawbacks of PWT system design observed during the evaluation centered on the flow control valves, and AMD collection from the Reynolds Adit for PWT treatment, as well as treated water management systems. Specifically, collection sumps, ditch lines, and settling tanks (Baker tanks) were insufficient for the evaluation. The collection sump used at the Reynolds Adit was insufficient to provide the proper volume and constant rate of flow of AMD to the treatment systems. As corrective action, the Aquafix unit was relocated prior to testing. Additionally, a new tap was designed and installed at the Reynolds Adit bulkhead to increase back pressure on the head through reducing the feed pipe diameter resulting in an increased flow rate. Feed lines were split directly off of this bulkhead tap to provide sufficient drainage for the evaluation.

The ditch line for the Aquafix system did not provide adequate mixing and aeration for oxidation of the AMD. Also, the Baker tanks used in place of settling ponds, due to space limitations, were of insufficient volume to permit settling and collection of metal hydroxide precipitate. As corrective action, an aeration tank was designed and constructed for the evaluation. This tank was situated into position upstream of the Baker tanks to permit gravity feeding of the treated wastewater stream. A rotary vane pump was used to move the water stream into the bottom of this aeration tank and to force the water stream through a fine bubbler to permit aeration of the stream. The aeration tank provided some relief to the problem of insufficient aeration for precipitation. However, after about three weeks into the demonstration, the Baker tanks became saturated and were unable to capture the reaction generated material.

The demonstration objectives outlined in the project's quality assurance project plan (QAPP) (Tetra Tech 2000) were not adversely impacted as a result of the changes described above.

3.2.4 Site Demobilization

The evaluation-scale treatment system was removed by CDPHE at the end of the demonstration. PWT system removal entailed the following:

- Removal and disposal of the treatment and settling ponds and disposal of substrate and pond sludge
- Backfilling treatment ponds with site material
- Removal of treatment system piping and other system hardware.

The PWT evaluation substrate and sludge materials generated under conditions of the evaluation were not hazardous materials, and potential disposal options included:

- Disposal at a municipal landfill
- Disposal in landfill biobeds (compost piles)

- Mixing with site mining waste rock and soil to provide needed organic matter

- Reuse in an interim ponded treatment system.

For this demonstration, the PWT system substrate and sludge waste materials were disposed of in a nearby municipal landfill.

3.3 Demonstration Methodology

The primary objective of the PWT technology evaluation was to determine the removal efficiency of each technology for the primary metal contaminants of interest (aluminum, copper, iron, manganese, and zinc) in the acid mine drainage. Influent and effluent samples from each of the technologies were collected and analyzed for aluminum, copper, iron, manganese, and zinc. For each technology, a removal efficiency was calculated for each pair of metal concentration data (influent and effluent) for each metal. In addition, an overall average removal efficiency was calculated using the average influent and average effluent concentration for each metal over the period of the evaluation. A 95 percent confidence interval was also constructed around the overall average removal efficiency for each metal. In addition, secondary objectives of the evaluation included the following:

- Characterize sludge from the settling ponds of the SAPS and Aquafix systems. Sludge samples were collected with a long handled, wide-mouth bottle (1 liter) sampler from several locations within each pond, and a composite sample was submitted for total metals (including cations) and water content analyses. The results of the water content analyses were used to evaluate sludge drying and disposal options. Finally, TCLP metals analyses were conducted on a sludge composite sample to determine RCRA hazardous waste characteristics.

- Determine the effectiveness of the SAPS polishing trenches. During the first half of the evaluation (7-8 weeks), the SAPS effluent was channeled through the limestone channel. During the second half of the evaluation, the SAPS effluent was channeled through the rock channel. Influent and effluent polishing trench samples were collected and analyzed for total metals, anions, alkalinity, TSS, and pH. Paired influent and effluent sample results were compared to determine the percent reduction of metals during polishing. The paired sample results were also used to determine increases or decreases in alkalinity and TSS as a result of polishing.

- Monitor use and degradation of the limestone and compost components of the SAPS pond, including microscopic observations of microbes in compost and gravimetric testing of limestone. This objective was not evaluated due to the short duration of the Summitville demonstration, which did not allow sufficient time for gravimetric and microbial testing.

- Determine the change in aquatic toxicity attributable to each treatment system. Toxicity studies on Rainbow trout (*Oncorhynchus mykiss*), Fathead minnows (*Pimephales promelas*), and water fleas (*Ceriodaphnia dubia*) were conducted with samples of both influent and effluent water for the SAPS technology. The toxicity tests with *P. promelas* and *C. dubia* were 48-hour, renewed, acute tests. A second series of tests using all three aquatic species were conducted using a 7-day growth and survival chronic test method. Influent and effluent water samples for toxicity testing were not collected from the Aquafix system due to the short duration of the Summitville demonstration.

- Estimate the capital and O&M costs for each technology.

3.4 Sampling, Analysis, and Measurement Procedures

Samples were collected at pre-determined points for each of the three technologies (see Figure 2). Table 3 provides a summary of the demonstration sampling locations. The location, number, and frequency of sample collection were defined in the project QAPP (Tetra Tech 2000), as were the matrices, analytical parameters, and analytical methods.

Due to the onset of winter and sub-freezing temperatures, evaluation participants determined that the evaluation would have to be terminated prematurely. Consequently, the frequency and number of samples were modified to collect a sufficient number of samples to allow for an evaluation of the technologies. The number of samples specified in the QAPP and the number of samples collected during this evaluation are provided on Table 3.

Table 3
Demonstration Sample Collection Summary

Treatment System	Sampling Location	Matrix	Objective	Parameters	Number Samples Specified	Number Samples Collected	Percent Complete
SAPS	SW-02	Influent water	P1	Metals	26	12	46
	SW-04	Effluent water	P1	Metals	26	12	46
	SW-02	Influent water	S1	Alkalinity, anions, TDS, TSS, pH	26	12	46
	SW-04	Effluent water	S1		26	12	46
	SW-01	Influent water	S1	Alkalinity, metals	13	9	69
	SP-01	Pond sludge	S2	Metals, percent solids, TCLP	4	3	75
	SP-02	Pond sludge	S2		4	1	25
	SP-03	Pond sludge	S2		4	2	50
	L501	Limestone	S3	Gravimetric testing	2	0	0
	CM01	Compost	S3	Microbial evaluation	2	0	0
	SW-02	Influent water	S3	Metals precipitation	1	0	0
	SW-03	Effluent water	S3		1	0	0
	LCW	Effluent water from polishing trenches	S5	Metals, anions, alkalinity, TDS, TSS, pH	26	2	8
	RCW				26	7	27
	SW-01	Influent water	S6	Toxicity	2	1	50

Table 3 (Continued)

Sample Collection Summary

Treatment System	Sampling Location	Matrix	Objective	Parameters	Number of Samples Specified	Number of Samples Collected	Percent Complete
SAPS (Continued)	SW-04	Effluent water	S6	Toxicity	2	1	50
Aquafix	AW-01	Influent water	P1	Metals	28	16	57
	AW-02	Effluent water	P1		28	16	57
	AW-01	Influent water	S1	Anions, alkalinity, TDS, TSS, pH	28	16	57
	AW-02	Effluent water	S1		28	16	57
	AP-01	Sludge	S2	Metals, percent solids, TCLP	4	2	50
	AP-02	Sludge	S2		4	2	50
	AW-01	Influent water	S6	Toxicity	2	1	50
	AW-02	Effluent water	S6		2	1	50

Notes:
TDS - Total dissolved solids
TCLP - Toxicity Characteristic Leaching Procedure
TSS - Total suspended solids

The evaluation of the SAPS and Aquafix technologies required collection of samples of water and sludge. Water samples were collected twice daily from the sampling ports into dedicated polyethylene dippers. Each individual sample was poured into a larger dedicated container for compositing. The composite sample was mixed gently and transferred to the sample containers and preserved. The samples for aquatic toxicity testing were collected in the same manner, but without preservatives.

Sludge samples were collected from the SAPS and Aquafix systems. The sludge samples were collected using a wide mouth bottle attached to a long rod. The rod/ bottle sampler was submerged into the sludge and the bottle was opened to allow the sludge to fill the bottle. Sludge samples were collected from five locations within each pond or tank and composited into a dedicated container. The samples were analyzed using the methods presented on Table 4.

3.5 SITE Evaluation Results

This section presents the results of the PWT technology evaluation conducted from August through October 2000. Aqueous chemistry data for the Reynolds Adit mine drainage at the Summitville site are presented, followed by the evaluation results for the two PWT technologies. Data indicate that both the SAPS and Aquafix systems removed significant percentages of aluminum, copper, iron, manganese, and zinc from the AMD even though the amount removed by both systems did not meet Summitville site project objectives. Data for the iron settling pond indicated a low removal efficiency from the pretreatment system. The low removal efficiency may have been attributable to the low pH of the AMD. Removal efficiencies varied for each system, and the relative efficiencies of each, are described in the following paragraphs. The average removal rates for metals in the Aquafix, SAPS iron settling pond, and SAPS pond are presented in Table 5.

Successive Alkalinity Producing System

Removal efficiencies for the SAPS ranged from a low of 11 percent for manganese to 97 percent for aluminum. The removal efficiency for the SAPS appeared to be declining at the end of the evaluation. This decline may have been due to a problem with the system, an indication the system needed to be flushed, or an artifact of chemistry changes in the influent source. Because of the short amount of time available to operate the system before winter, and the length of time required to refill the SAPS with water, the SAPS was not flushed until the end of the evaluation.

Aquafix System

Removal efficiencies of the initial short-term operation of the Aquafix system ranged from 97 percent for aluminum and manganese to 99 percent for copper, iron, and zinc. The system was shut down prematurely due to clogging of the system.

3.5.1 Summitville Mine Drainage Chemistry

Summitville surface and mine waters are characterized by high concentrations of metals such as aluminum, iron, and copper; high sulfate levels; and, low pH. These conditions result when sulfide minerals come in contact with oxygen and water to produce metal contaminated acid mine drainage. The acidity permeates the rock and further releases more metals. The metals, sulfate, and acidity (protons) are taken up by infiltration water and transported in surface groundwater, to seeps or deeper into the mine workings and eventually discharged from the Chandler, Iowa, or Reynolds Adits.

Water from the Reynolds Adit was selected to evaluate the PWT technologies at the Summitville site. In general, the pH of the site water ranges from 2.7 to 3.5. Aluminum, copper, and iron are the primary contaminant metals, with lesser concentrations of manganese, nickel, and zinc. Table 2 summarizes analytical results for the Reynolds Adit and compares the results against CDPHE water quality standards.

3.5.2 Trend Analysis and Data Reduction

This section provides trend analyses and data reduction information for data from both PWT technology evaluations.

SAPS Technology

Figures 1a through 1e in Appendix A display the inflow and outflow trend plots for the SAPS technology (for aluminum, copper, iron, manganese, and zinc, respectively). Also, Figure 1f shows the trend plot for pH. In each plot, the inflow sample data collected on September 13 is shown as day 1. Additionally, since the assumed residence time for this system was 4 days, the outflow levels have been shifted 4 days in to align with their

Table 4
Summary of Analytical Methods

Matrix	Parameter	Analytical Method
Water	Total Metals	SW-846, 3010. 6010B [a]
Water	Major Anions (chloride and sulfate)	MCAWW [b] Method 300.0
Water	Alkalinity	MCAWW [b] Method 310.1
Water	pH	SW-846 9040
Water	Total Suspended Solids	MCAWW [b] Method 160.2
Water	Total Dissolved Solids	MCAWW [b] Method 160.1
Water	Toxicity	WET Method [c]
Sludge	Moisture Content	SMEWW 2540B
Sludge	TCLP [d] Metals	SW-846 1311 301/6010 [b]
Sludge	Metals (total) [e]	SW-846 3050 6010B [a]

Notes:

SMEWW	Standard methods for examination of water and wastewater
a	EPA SW846 (1997)
b	Methods for chemical analysis of water and wastes
c	Whole effluent toxicity test
d	Toxicity characterization Leaching Procedure
e	Metals (total) aluminum, calcium, copper, iron, magnesium, manganese, potassium, sodium, and zinc

Table 5
Summary of Contaminant Removal Efficiency for Metals

Metal	Aquafix (Percent)	SAPS Iron Settling Pond (Percent)	SAPS Pond Removal (Percent)
Al	97	3	97
Cu	99	0	90
Fe	99	6	64
Mn	97	<1	11
Zn	99	3	57

corresponding inflow levels in each plot. In each plot, the inflow concentration levels represent the influent samples collected entering the SAPS pond (location SW-02). Likewise, the outflow concentration levels represent the effluent samples leaving the SAPS settling pond (location SW-04). It should also be noted that data collected after day 39 is out of control likely due to a problem with the SAPS system or chemistry changes in the influent source as mentioned in Section 3.5. Up to this point, all outflow concentration levels appeared relatively stable.

Aquafix System

Figures 2a through 2e in Appendix A display the inflow and outflow trend plots for the Aquafix system (for aluminum, copper, iron, manganese, and zinc, respectively). Also, Figure 2f shows the trend plot for pH. In each plot, the sample data collected on September 19, 2000 are shown as day 1. Additionally, since the assumed residence time for this system is 2 days, the outflow levels have been shifted 2 days to align with their corresponding inflow levels in each plot. In each plot, the inflow concentration levels represent the influent samples collected from the Reynolds Adit location (location AW-01). Likewise, the outflow concentration levels represent the effluent samples collected from the Aquafix storage tanks (Baker tanks) (location AW-02).

All five of these plots reveal similar patterns; that is, extremely reduced outflow concentration levels through day 20 (October 9), and then a corresponding rapid increase in outflow concentration levels starting on October 10 (day 21). These latter outflow "spikes" represent the Aquafix system going out of control, due to the depletion of the lime additive. Note the increase in pH as shown in Figure 2f as a result. Up to this point, all outflow concentration levels appeared relatively stable. Additionally, most of the inflow levels over this same time frame also appeared to be relatively stable, although clearly more variable.

The systematic collection of inflow and outflow samples occurred between September 19 to September 29 (on a 2-day interval) and October 4 to October 12 (on a 1-day interval). Within the October 4 to October 12 time frame, eight paired inflow/outflow observations exist. It should be noted that data collected from October 9 through October 12 appears to be out of control likely due to the depletion of the lime additive for the Aquafix system as described above. Within the September 19 to 29 time frame, three paired inflow/outflow observations exist, and a fourth pair can be derived for September 21 by averaging the September 19 and September 23 influent samples.

Figures 1a - 1f (SAPS) and 2a - 2f (Aquafix system) displays the chemical concentration levels for the above-mentioned 10 inflow/outflow observations for aluminum, copper, iron, manganese, zinc, and arsenic, respectively. These reduced data sets were used for all statistical analyses. As explained above, the influent concentration levels shown for September 21 represent interpolated values. Additionally, note that non-detects were reported on October 7 for the copper and manganese outflow (effluent) concentration levels.

3.5.3 Toxicity Testing Results

Three water samples from the Summitville site were shipped to the U.S. EPA Andrew W. Briedenbach Environmental Research Center's laboratory in Cincinnati, Ohio. These samples consisted of influent and effluent water samples from the SAPS system. A series of acute aquatic toxicity tests with *Pimephales promelas* (fathead minnows) and *Ceriodaphnia dubia* (water fleas), and chronic aquatic toxicity tests with *Oncorhynchus mykiss* (rainbow trout) were conducted on these samples. The purpose of these tests was to establish the level of toxicity for the discharge from the mine site and to evaluate the effectiveness of the SAPS treatment process. Influent and effluent water samples from the Aquafix system were also expected to be collected for toxicity testing but due to the short duration of the Summitville demonstration the samples were not collected.

Samples were collected on October 14 and transported from the site back to Denver for shipment. Due to the type of container originally used for collection, the samples were transferred on October 15 into 20-liter containers. The samples were shipped on October 16 and arrived at EPA's laboratory on October 19. Tests using all three samples were started on the same day. The chemistry data from these samples were used to estimate the dilution series to use with each sample for each species in the acute tests. After the first 24 hours of exposure, the mortality in the low concentration of each sample was excessive for both species, so all tests were restarted using a lower dilution series. These tests were successful. The toxicity levels found in the *P. promelas* acute tests were then used to develop the dilution series used with each sample in the *O. mykiss* chronic tests, started on October 23. No problems were encountered

with the dilution series used for each of these samples. In addition to the tests with the samples, zinc acute and/or chronic reference toxicity tests were conducted to provide a measure of the sensitivity of the test animals when compared to a standard toxicant.

Routine initial chemical parameters (Table 6) were determined and toxicity tests were started on arrival of the samples. The tests with *P. promelas* and *C. dubia* were 48-hour, renewed, acute tests, conducted

at 20 °C. Each sample was analyzed using both acute tests. In addition, all three samples were analyzed using an *O. mykiss* 7-day, growth and survival test to provide a measure of the sensitivity of this method versus the two acute methods, as well as to provide a subsample of chronic test data.

All tests were conducted using moderately hard reconstituted water as the control and dilution water. Test conditions were maintained in accordance with method requirements. The *P. promelas* used in this study were 3 days old, provided from EPA's laboratory culture unit. The *C. dubia* were less than 24 hours old, provided from EPA's laboratory culture unit. The *O. mykiss* used were 18 days old, 5 days post swimup, provided by Troutlodge, Sumner, Washington. The trout were received on October 19 and held at 15 °C for 3 days until the start of the trout tests on October 23.

All values for a lethal concentration for 50 percent of the population (LC50) were determined using Trimmed Spearman-Karber, version 1.5, which adjusts for control mortality. The survival No Observed Acute Effect Level (NOAEL), the chronic survival No Observed Effect Concentration (NOEC), and the chronic growth NOEC were determined using Dunnett's, version 1.5, and the IC25 values were determined using ICP version 2.0.

Results and Discussion

As stated above, both the *C. dubia* and *P. promelas* acute tests needed to be restarted, after the 24-hour results showed excessive mortality in the low test concentration in each sample for both species. The tests restarted with lower dilution concentrations for each sample/species produced survival/mortality results that could be used to generate LC50 values for all species in all tests. These results also produced data that allowed the determination of NOAEL values, either through actual data analysis, or through the use of the estimation guidelines described above.

The results from the three *C. dubia* tests (Table 7) showed a high level of toxicity from all three samples to the animals. For the mine discharge sample, SW-01, the LC50 value was 0.01 percent, with an estimated NOAEL of 0.005 percent. For the first treatment sample, SW-04, the LC50 value was 0.08 percent, with an NOAEL of 0.05 percent. For the second treatment sample, RCW, the LC50 value was 0.07 percent, with an estimated NOAEL of 0.025 percent. The results from the zinc reference toxicant test showed an LC50 value of 270.8 micrograms per liter (µg/L). This value was somewhat high compared to the historical data for this toxicant, which shows an average LC50 value of 193.4 µg/L, with a range of 103 µg/L (-2 standard deviation) to 284 µg/L (+2 standard deviation). While high, the zinc reference toxicant value was in the acceptability range.

The results for the three *P. promelas* tests (Table 7) also showed a high level of toxicity from all three samples to the animals. For sample SW-01, the LC50 value was 0.29 percent, with an NOAEL of 1.56 percent. For the first treatment sample, SW-04, the LC50 value was 2.18 percent, with an NOAEL of 1.56 percent. For the second treatment sample, RCW, the LC50 value was 2.12 percent, with an NOAEL of 1.56 percent. The zinc reference toxicant test resulted in an LC50 value of 957.6 µg/L. The historical data for this toxicant and test method shows an average LC50 value of 722.2 µg/L, with a range of 208 µg/L (-2 standard deviation) to 1,236 µg/L (+2 standard deviation).

The results from the rainbow trout tests showed high levels of toxicity as well. For sample SW-01, the survival NOEC value was 0.1 percent, the growth NOEC value was greater than 0.1 percent, and the IC25 value 0.18 percent. For the first treatment sample (SW-04), the survival NOEC was 1 percent, the growth NOEC greater than 1 percent, and the IC25 value 1.18 percent. For the second treatment sample, RCW, the survival NOEC was 1 percent, the growth NOEC greater than 1 percent, and the IC25 1.29 percent. For the zinc reference toxicant test, the survival NOEC was 125 µg/L, the growth NOEC value was 62.5 µg/L, and the IC25 value was 159.8 µg/L. This compares well to the historical zinc reference toxicant data for this test method, which has an IC25 value of 138.1 µg/L, with a range of 55.1 (-2 standard deviation) to 221.1 (+2 standard deviation).

Table 6
Toxicity Test Water Quality

Sample	Matrix	Temperature (C)	pH (SU)	Alkalinity (mg/L)	Hardness (ppm)	Conductivity (µS/cm)	DO (ppm)
SW-01	Influent water to iron settling pond	15.1	2.96	N/A*	20,000	3,160	7.0
SW-04	Effluent water from SAPS settling pond	14.9	4.17	N/A*	3,000	3,500	7.5
RCW	Rock channel effluent water	15.4	4.16	N/A*	2,500	3,330	7.5
LCW	Limestone channel effluent water	23.5	7.95	60	96	344	8.4

Notes:
*If pH is below 4.7, alkalinity cannot be determined
C Degrees Celsius
µS/cm Micro siemens per centimeter
DO Dissolved oxygen
mg/L milligrams per liter
N/A Not applicable
ppm Parts per million

Table 7
Comparison of Survival Results for *Ceriodaphnia dubia*, *Pimephales promelas*, and *Oncorhynchus mykiss* using Samples from Summitville Mine Drainage and Pilot Treatment Effluents

Sample	Matrix	Cerio 48-hour LC50	FH 48-hour LC50	Trout 7-day LC50	Trout NOEC
SW-01	Influent water to iron settling pond	0.01%	0.29	0.25%	0.1%
SW-04	Effluent water from SAPS settling pond	0.08%	2.18	1.57%	1%

Notes:
µg/L Micrograms per liter
Cerio *Ceriodaphnia dubia*
FH Fathead minnow
LC50 Lethal concentration for 50 percent of the population
NOEC No observed effect concentration in 7-day period

Conclusions

Table 7 summarizes the results of all species tested with Summitville drainage with the SAPS treatment. Based on these results, the order of sensitivity to the Summitville drainage is as follows:

C. dubia is more sensitive than rainbow trout and the fathead minnow. The SAPS system reduced toxicity by 7-8 fold for *C. dubia*, at 10-fold for rainbow trout, and about 5-fold for the fathead minnow. However, a substantial amount of toxicity remains. A 100-fold greater reduction needs to be accomplished to have a no acute toxicity to rainbow trout, a 1,000-fold reduction in both treatments is needed to have a no acute effect on *C. dubia,* and a 50-fold reduction is needed for no acute effects on fathead minnows.

3.5.4 Attainment of Evaluation Objectives

This section summarizes the preliminary laboratory analytical data from field sampling and in-field observations as they relate to assessment of the primary and secondary objectives.

3.5.4.1 Removal Efficiencies

The primary objective of this PWT technology evaluation was to determine removal efficiencies for the SAPS and Aquafix technologies. Data indicate that both the SAPS and Aquafix systems removed significant percentages of aluminum, copper, iron, manganese, and zinc from the AMD. Data for the iron settling pond indicated a low removal efficiency from the pretreatment system. The low removal efficiency may have been due to the low pH of the AMD (ferric iron may have been soluble at the pH of the oxidation pond used in pretreatment of the Reynolds Adit AMD). Removal efficiencies varied for each system and the relative efficiencies are described below. Data trends and efficiency calculations are discussed in this subsection by treatment system. Table 8 presents the removal efficiencies with 95 percent upper and lower confidence limits for aluminum, copper, iron, manganese, and zinc.

Successive Alkalinity Producing System

Removal efficiencies for the SAPS ranged from a low of 11 percent for manganese to 97 percent for aluminum. It should be noted that the removal efficiency for the SAPS appeared to be declining at the end of the evaluation. This decline may have been an indication that the system needed to be flushed or

an artifact of chemistry changes in the influent source. Because of the short amount of time available to operate the system before winter, and the length of time required to refill the SAPS with water, the SAPS was not flushed until the end of the evaluation.

Aquafix System

Removal efficiencies for the Aquafix ranged from 97 percent for aluminum and manganese to 99 percent for copper, iron, and zinc.

Secondary objectives of this PWT technology evaluation were to characterize the resulting sludge, determine the effectiveness of the SAPS polishing trenches, determine the change in aquatic toxicity of the mine drainage attributable to each system, and estimate capital and operations and maintenance costs for each technology. These secondary objectives are discussed below.

3.5.4.2 Pond Sludge Characteristics and Estimated Volume

A summary of average concentrations for aluminum, copper, iron, manganese, and zinc in sludge samples collected from the Aquafix and SAPS systems during the evaluation is provided in Table 9. Sludge samples from the SAPS pond were also characterized for disposal using TCLP at the conclusion of the evaluation. The sludge samples met RCRA criteria for disposal as unregulated solid waste. Consequently, the SAPS pond sludge, as tested, would not need to be disposed of at a RCRA Subtitle C landfill. The average concentrations of TCLP metals in the SAPS pond sludge samples along with the RCRA regulatory criteria are provided in Table 10. Sludge from the Aquafix settling tanks was not characterized using TCLP. The majority of solids in the settling tanks remained suspended, and the high water content in the sludge precluded sampling the solids for TCLP analysis.

3.5.4.3 Use and Degradation of Materials in SAPS

A cage that contained a preweighed amount of lime was inserted into the SAPS pond at the beginning of the evaluation, but the pond froze before the cage could be retrieved for post-evaluation weighing and pore-space evaluation. (Eventual clogging of the pore spaces in the

Table 8
Removal Efficiencies with 95% Upper and Lower Confidence Limits

Metal	SAPS			Aquafix		
	95% LCL	Mean RE	95% UCL	95% LCL	Mean RE	95% UCL
Al	95.99	97.60	99.21	95.76	97.24	98.71
Cu	85.29	90.51	95.73	97.59	98.66	99.73
Fe	52.94	65.35	77.76	96.86	98.15	99.44
Mn	3.37	14.79	26.21	96.18	97.76	99.33
Zn	12.49	42.54	72.58	97.37	98.44	98.44

Notes:
RE Removal Efficiency
UCL Upper Confidence Limit
LCL Lower Confidence Limit

Table 9
Average Metals Concentrations in Sludge Samples from Aquafix and SAPS Systems

Metal	Aquafix Baker Tank Sludge (mg/kg)	SAPS Iron Settling Pond Sludge (mg/kg)	SAPS Pond Sludge (mg/kg)	SAPS Settling Pond Sludge (mg/kg)
Al	78,700	12,900	5,240	53,733
Cu	27,525	2,340	1,146	15,333
Fe	193,250	221,500	136,850	120,667
Mn	7,125	722	103	2,110
Zn	7,870	654	101	3,107

Notes:
mg/kg milligrams per kilogram

Table 10
Average TCLP Metals Concentrations in SAPS Pond Sludge Samples

TCLP Metal	SAPS Pond Sludge (mg/L)	RCRA Regulatory Criteria (mg/L)
Arsenic	ND	5.0
Barium	0.12	100
Cadmium	0.012	1.0
Chromium	0.005	5.0
Lead	0.061	5.0
Selenium	ND	1.0
Silver	ND	5.0
Mercury	NA	0.2

Notes:
mg/L milligrams per liter
ND Not detected
NA Not analyzed

limestone with precipitated metal hydroxides and gypsum can be a limiting factor with the SAPS system).

3.5.4.4 Effectiveness of the SAPS Rock Drain Polishing Trench

Data from the channel samples to determine polishing effectiveness are inconclusive. Fluctuating pH measurements and low removal efficiencies were obtained that could be attributed to site specific construction features or polishing system performance.

3.5.4.5 Changes in Aquatic Toxicity

At the end of the evaluation period, bulk samples were obtained from the SAPS for toxicity testing. Post-treatment samples showed that toxicity was reduced by 7 to 8 times for *C. dubia*, about 10 times for rainbow trout, and about 5 times for the fathead minnow. A substantial amount of toxicity remained in the post-treatment water. A 100-times greater reduction in the concentration of metals is needed to remove acute toxicity to rainbow trout, and a 1,000-times reduction in metals is needed to remove acute toxicity to *C. dubia.* A 50-times reduction is required to achieve the level of no acute effect to fathead minnows.

3.5.4.6 Flow Rate and Mass Metals Loadings

Flow rates were recorded for both PWT systems during every sampling event. Flow rates for the SAPS remained relatively constant at about 5 gpm. Influent for the SAPS came from the Reynolds Adit sumps from evaluation startup until low water levels prohibited using the sumps as the source of water in early September. The water pumps were shut down and the system plumbing was redesigned to use water from the Reynolds Adit Plug under gravity feed. At the time the systems were shut down, 42 percent of the total flow had originated from the sump, where water had lower concentrations of metals than the water in the Reynolds Adit. Therefore, the metals in the influent concentrations were averaged for each source of influent, then weighted by the percentage of the total flow for each source of influent water. Concentrations of metals in the influent averaged 240 mg/L per liter of aluminum, 102 mg/L of copper, 570 mg/L of iron, 28 mg/L of manganese, and 26.7 mg/L of zinc. Flow rates through the Aquafix system fluctuated frequently affecting pH levels (as a result of the varying amounts of lime being added) and residence time in the system. Flow rates in the Aquafix system varied from about 16 gpm to 21 gpm, with an average goal of flow at 19 gpm. The influent to the Aquafix system was all from the Reynolds Adit during the period it was sampled.

The influent metals concentrations to the Aquafix system averaged 247 mg/L of aluminum, 112 mg/L of copper, 684 mg/L of iron, 33 mg/L of manganese, and 32 mg/L of zinc. Because of the length of time needed to settle the precipitate in the Baker tanks, the inflow to the tanks was split, with about 50 percent of the flow going to the tanks and 50 percent directed back into untreated surface flow drainage. Removal efficiencies of the Aquafix system were much higher than for the SAPS for copper, iron, manganese, and zinc, and was the same for aluminum. However, the Aquafix removal efficiencies decreased when the pH could not be maintained at the optimal level of around 8.0. Precipitate was drained from the second Baker tank as the volume of precipitate in the tank increased. This drainage flowed to the Summitville Drainage Impoundment, where it was captured and subsequently treated by the on-site treatment plant.

3.5.5 Design Effectiveness

The following sections discuss the effectiveness of the PWT systems tested at the Summitville site. This discussion focuses on general design parameters and factors that affect each cell.

The basic design of the PWT evaluation system consisted of a sump for collection of AMD at the Reynolds Adit, piping from the sump to the influent weir, the SAPS settling pond, and a bypass pipe. The system was designed to be driven by gravity flow. The sump collected the mine drainage and provided adequate hydraulic head to drive the mine drainage to the SAPS pond and Aquafix units. The influent weir partitioned the mine drainage. From the influent weir, the mine drainage was channeled to a ball valve that separated flow to the treatment systems.

Construction materials associated with this design were generally inexpensive, readily available, and easily transported to remote areas. Installation techniques were also straightforward.

The major drawbacks of this design observed during the evaluation at the Summitville site centered on the flow control valves, and AMD collection from the Reynolds Adit for PWT treatment, as well as treated water management systems. Specifically, the collection sump, ditch lines, and settling tanks (Baker tanks) were not

sufficient for the evaluation. The collection sump utilized at the Reynolds Adit was not sufficient to provide the proper volume and constant rate of flow of AMD delivery to the treatment systems. For the Aquafix system, the ditch line did not provide adequate mixing and aeration for oxidation of the AMD. Further, the Baker tanks used in the evaluation did not provide sufficient volume or residence time for long-term precipitation and removal of the metals from the treatment system discharge. The limestone and rock polishing channels were not sufficiently sized to provide added removal efficiency to the PWT systems.

In summary, PWT technologies are suitable for treatment of AMD. The application of these technologies at the Summitville site proved extremely challenging due to the severity in quality of the AMD, high altitude conditions, limited site access, and limited land area for system installation.

4
Economic Analysis

This section presents cost estimates for using PWT systems to treat mine drainage with water chemistry similar to the AMD from the Reynolds Adit at the Summitville site. The baseline scenario used for developing this cost estimate was a 5 gpm flow rate for the SAPS, an 18 gpm flow rate for the Aquafix system , and a 15-year system life. The baseline costs were then adjusted for varying flow rates and treatment periods to develop cost estimates for other cases. Additional cases based on a system life of 15 years were determined for 25 gpm and 100 gpm flow rates.

Cost estimates presented in this section are based primarily on data compiled during the SITE demonstration at the Summitville site. Additional cost data were obtained from standard engineering cost reference manuals (Means 2000). Costs have been assigned to 11 categories applicable to typical cleanup activities at Superfund and RCRA sites (Evans 1990). Costs are presented in year 2000 dollars and are considered estimates, with an accuracy of plus 50 percent and minus 30 percent.

4.1 Basis of Economic Analysis

Several factors affect the costs of treating AMD with PWT systems. These factors generally include flow rate, type and concentration of contaminants, physical site conditions, geographical site location, and treatment goals. Treatment pond sludge will require off-site disposal, which may include pre-treatment costs. The characteristics of the sludge generated by the PWT system will also affect disposal costs. Mine drainage containing aluminum at 240 mg/L, arsenic at 1.5 mg/L, copper at 102 mg/L, iron at 570 mg/L, manganese at 28 mg/L, and zinc at 27 mg/L was selected for this economic analysis. The following paragraphs present additional assumptions and conditions as they apply to each case.

For each case, this analysis assumes that the SAPS and Aquafix systems will treat contaminated mine drainage continuously, 24 hours per day, 7 days per week. An average metals removal efficiency of 96 percent was assumed for all cases.

Further assumptions about application of PWT systems for each case include the following:

- A residence time of 336 to 360 hours for the baseline SAPS application, and a minimum of 48 hours for the baseline Aquafix application is recommended for adequate metals removal.

- The SAPS pond, which was assumed to be 9 feet deep and 13,500 cubic feet in volume, will provide 336- to 360-hours of residence time at a flow rate of 5 gpm (pond size is directly proportional to flow rate). The water level in the pond must also be sufficiently deep so that diffusion of dissolved oxygen at depth is prevented.

- A mechanism is assumed to be required to maintain the water level and flow rates for both the SAPS and Aquafix systems at appropriate levels.

- Organic compost and limestone material will require removal every five years.

- Residual substrate is not a RCRA hazardous waste; thus, it will be dewatered on site and can be recycled or disposed of at an industrial or municipal landfill.

- Treatment pond sludge, depending on the site conditions and period of operation may require classification under RCRA as hazardous waste, even though the limited sludge samples that were evaluated in the evaluation were not hazardous. Pond sludge must be sampled and evaluated for RCRA criteria

prior to disposal to determine the need for pretreatment, handling, and disposal requirements.

This analysis assumes that aquatic-based standards are most appropriate and the attainment of these standards depends on the affected organisms, receiving waters, and volume of mine drainage. Attainment of aquatic based standards may not be feasible in all cases for the technology as tested during this evaluation.

The following assumptions were also made for each case in this analysis:

- The site is located within 200 miles of the disposal location.
- The site will allow for gravity flow of the mine drainage through the treatment system.
- There is a minimum of 1 to 1.5 acres available at the site to accommodate treatment and settling ponds and staging areas, construction equipment, and sampling and maintenance storage area.
- A staging area is available for dewatering spent substrate.
- Access roads exist at the site.
- The treatment goal for the site will be to reduce metals contaminant levels by 96 percent.
- Spent substrate will be dewatered and disposed of off site.
- One influent water sample and two effluent water samples will be collected monthly and two composite substrate samples will be collected quarterly to monitor system performance.
- One part-time operator will be required to inspect the system, collect all required samples, and conduct minor maintenance and repairs.

4.2 Cost Categories

Cost data associated with the PWT technologies have been assigned to one of the following 11 cost categories: (1) site preparation; (2) permitting and regulatory requirements; (3) capital equipment and construction; (4) startup; (5) labor; (6) consumables and supplies; (7) utilities; (8) residual and waste shipping and handling; (9) analytical services; (10) operation maintenance and modifications; and (11) demobilization. Costs associated with each category are presented in the sections that follow. Some sections end with a summary of significant costs within the category. Table 11 presents the cost breakdown for the SAPS variable treatment volumes at varying flow rates. Table 12 presents the cost breakdown for the Aquafix variable treatment volumes at varying flow rates. The tables also present total one-time, fixed costs, and total variable O&M costs; the total project costs; and the costs per gallon of water treated for each system.

4.2.1 Site Preparation Costs

Site preparation for both technologies include administration, pilot-scale testing, and mobilization costs. Additional space would be needed beyond the assumed 1 to 1.5 acres if additional pretreatment ponds are required. A solid gravel (or ground) surface is preferred for any remote treatment project. Pavement is not necessary, but the surface must be able to support construction equipment. This analysis was performed on the basis that only moderate modifications will be required for construction of the treatment and settling ponds.

Administrative costs, such as legal searches and access rights, are estimated to be $10,000.

A pilot-scale study involves an assessment of AMD characteristics and an evaluation to determine the properties for the alkaline producing systems to provide optimized treatment. This treatability study is estimated to cost $35,000.

Mobilization involves transporting all construction equipment and materials to the site. For this analysis, it is assumed that the site is located within 100 miles of a city where construction equipment is available. The total estimated mobilization cost will be $5,000.

For each case, total site preparation costs are estimated to be $50,000.

4.2.2 Permitting and Regulatory Requirements

Permitting and regulatory costs vary depending on whether treatment occurs at a Superfund site and on the disposal method selected for treated effluent and any solid wastes generated. At Superfund sites, remedial actions

Table 11
SAPS Technology Costs for Different Treatment Volumes*

Cost Categories	System Life at 15 years					
	5 gpm		25 gpm		100 gpm	
Fixed Costs						
Site Preparation	$50,000		$50,000		$50,000	
Administrative		$10,000		$10,000		$10,000
Pilot-Scale Treatability Study		35,000		35,000		35,000
Mobilization		5,000		5,000		5,000
Permitting and Regulatory Requirements	5,000		5,000		5,000	
Capital Equipment	138,100		162,600		373,900	
System Design		50,000		50,000		50,000
Excavation and Site Preparation		11,000		16,000		32,000
Compost and Limestone Substrate		11,500		30,600		161,700
SAPS Treatment Pond Construction		54,300		54,300		108,600
Piping and Valves		8,800		9,200		17,600
Storage Building		2,500		2,500		4,000
Startup	1,500		3,000		6,000	
Demobilization	27,100		114,500		370,000	
Excavation and Backfilling		7,000		14,000		28,000
Treatment Pond Sludge Disposal		8,100		12,500		50,000
Substrate Disposal		12,000		60,000		180,000
Total Fixed Costs	221,700		335,100		804,900	
Variable Costs						
Labor	153,000		153,000		153,000	
Operations and Maintenance Staff		153,000		153,000		153,000
Consumables and Supplies	10,000		10,000		10,000	
Personal Protective Equipment						
Construction Management	25,000		51,000		76,000	
Analytical Services	324,300		324,300		324,300	
Maintenance and Modifications	67,600		110,400		300,800	
Annual Maintenance		25,000		40,000		60,000
Pond Sludge Removal		32,400		50,000		200,000
Substrate Removal and Replacement		10,200		20,400		40,800
Total Variable Costs	579,900		648,700		864,100	
Total Costs 15 Year Life	801,600		983,800		1,669,000	
Cost Per Year	53,400		65,600		111,300	
Total Cost Per Gallon Treated	$0.020		$0.005		$0.002	

Note: *Costs are based on September 2000 dollars, total costs rounded to the nearest $100.

Table 12
Aquafix Technology Costs for Different Treatment Volumes*

Cost Categories	System Life 15 Years					
	18 gpm		25 gpm		100 gpm	
Fixed Costs						
Site Preparation	$50,000		$50,000		$50,000	
Administrative		$10,000		$10,000		$10,000
Pilot-Scale Treatability Study		35,000		35,000		35,000
Mobilization		5 ,000		5,000		5,000
Permitting and Regulatory Requirements	5,000		5,000		5,000	
Capital Equipment	274,600		323,300		913,300	
System Design		50,000		50,000		50,000
Excavation and Site Preparation		14,000		16,000		32,000
Settling Pond Construction		75,000		81,400		240,000
Aquafix Unit		21,800		21,800		21,800
Pebble Quicklime		103,300		143,600		547,500
Piping and Valves		8,000		8,000		18,000
Storage Building		2,500		2,500		4,000
Startup	3,000		3,000		6,000	
Demobilization	60,400		80,500		272,000	
Excavation and Backfilling		8,000		10,000		20,000
Settling Pond Sludge Disposal		30,400		40,500		162,000
Substrate Disposal		22,000		30,000		90,000
Total Fixed Costs	$393,000		$462,800		$1,246,300	
Variable Costs						
Labor	153,000		153,000		153,000	
Operations Staff		153,000		153,000		153,000
Consumables and Supplies	10,000		10,000		10,000	
Personal Protective Equipment						
Construction Management	12,000		26,000		42,000	
Analytical Services	324,300		324,300		324,300	
Maintenance and Modifications	71,200		110,400		295,200	
Annual Maintenance		25,000		40,000		60,000
Pond Sludge Removal		36,000		50,000		194,400
Substrate Removal and Replacement		10,200		20,400		40,800
Total Variable Costs	$570,500		$623,700		$824,500	
Total Costs - 15 Year Life	$963,500		$1,085,500		$2,070,800	
Cost Per Year	$64,200		$72,400		$138,000	
Total Cost Per Gallon Treated	$0.007		$0.005		$0.003	

*Costs are based on September 2000 dollars, rounded to the nearest $100.

must be consistent with ARARs, environmental laws, ordinances, and regulations, including federal, state, and local standards and criteria. In general, ARARs must be identified on a site-specific basis. At an active mining site, a NPDES permit will likely be required and may require additional monitoring records and sampling protocols, which can increase permitting and regulatory costs. For each case represented in Tables 11 and 12, total permitting and regulatory costs are estimated to be $5,000.

4.2.3 Capital Equipment

Capital costs include all PWT systems design and construction materials and a site building for housing sampling, monitoring, and maintenance equipment. Construction materials for each system include sand, synthetic liners, geotextile liners, PVC piping, valves, concrete vaults or sumps, weirs, and other miscellaneous materials specific to each technology. Capital costs for the baseline PWT systems are presented in Tables 11 and 12.

Site preparation and excavation includes clearing the site of brush and trees, excavation of the treatment ponds, grading the site, and construction of the ponds. The total cost of site preparation and excavation for the SAPS system is $11,000. The total cost of site preparation and excavation for the Aquafix system is $14,000.

Construction of the SAPS treatment ponds involves subgrade preparation and installation of a sand layer, liner, piping distribution, and collection systems. Also included is piping to and from the treatment ponds as well as system bypass piping and weirs at the influent of the treatment and settling ponds to control flow through the system. The estimated cost for construction of the treatment ponds is $54,300. The cost of distribution piping is estimated at $8,800, and the cost of substrate materials is $11,500. System design is estimated to be $50,000.

A small building is required for storing sampling equipment and providing work space for the SAPS operator. The cost for a simple building with electricity has been estimated at $2,500.

Total fixed costs, for installation of the 5 gpm SAPS system, as tested, is $221,700. This cost also includes startup and demobilization and these costs are discussed further in the following sections.

Variable costs for the SAPS include labor for operations and maintenance staff, consumables and supplies, annual construction management support, analytical services, annual maintenance and modifications that includes pond sludge removal and replacement of substrate. The total variable costs for the baseline system is $579,900. Variable costs are discussed in more detail in the following sections.

The total capital cost for the baseline 5 gpm SAPS system for the 15-year system life is $801,600. For the 25 gpm SAPS system, this cost is increased to $983,800 primarily from increases in both the fixed and variable materials costs with larger quantities. For the 100 gpm SAPS system, the total cost is $1,669,000, with the increases in material quantities.

For the baseline Aquafix system, substrate costs and capital equipment costs will differ from those for the SAPS system, since distribution equipment is used in place of the treatment pond. Pebble quicklime was used to increase alkalinity in place of compost and crushed limestone. The annual cost of pebble quicklime for the baseline Aquafix system is $103,300 and the cost of the Aquafix unit is $21,800. Settling pond construction, which includes subgrade preparation and installation of a sand layer, liner, piping distribution and collection systems cost is $75,000 for the baseline Aquafix system. Distribution piping from dispensing unit to the source and the settling pond cost is $8,000 for the baseline system.

A small building is also required for storing sampling equipment and providing work space for the Aquafix operator. The cost for a simple building with electricity has been estimated at $2,500.

Total fixed costs for installation of the baseline 18 gpm unit is $393,000. This cost also includes startup and demobilization and these costs are discussed further in the following sections.

Variable costs for the Aquafix system are similar to the SAPS system with the exception of maintenance and modifications costs. For the baseline system the maintenance costs, which includes costs for annual maintenance, substrate removal and replacement, and pond sludge removal and disposal are $71,200. The total variable costs for the baseline Aquafix system is $570,500, and the total capital cost for this 18 gpm system, for the 15-year system life is $963,500. For the 25 gpm system, the capital cost is increased to $1,085,500 with

increased quantity of materials. For the 100 gpm system, the increase in material quantity drives the capital cost to $2,070,800.

4.2.4 Startup

Startup requirements are minimal for a PWT system. System startup involves introducing flow to the PWT with frequent inspections to verify proper hydraulic operation. Operators are assumed to be trained in health and safety procedures. Therefore, training costs are not incurred as a direct startup cost. The only costs directly related to system startup are labor costs associated with more frequent system inspection, and will increase with the size of the system. Startup costs are estimated at $1,500 for the SAPS system and $3,000 for the Aquafix system.

4.2.5 Labor

For either system, labor costs include a part-time technician to sample, operate, and maintain the system. Once the system is functioning, it is assumed to operate continuously at the design flow rate. One technician will monitor the system on a weekly basis. Weekly monitoring will require several hours 2 to 3 times per week to check flow rate and overall system operation. Sampling is assumed to be conducted once a month and will require two technicians for 2 hours. Based on average labor rates, these requirements equate to an estimated cost of $153,000 for each system over a 15-year period.

4.2.6 Consumables and Supplies

For either system, the only consumables and supplies used during PWT operations are disposable PPE. Disposable PPE includes Tyvek coveralls, gloves, and boot covers. The treatment system operator will wear PPE when required by health and safety plans during system operation. The estimated cost of PPE for each system over a 15-year period is $10,000.

4.2.7 Utilities

For either system, utilities used by the PWT systems are negligible. The PWT systems require no utilities for operation. The only utility required is for electricity for lights in the on-site storage building and for charging monitoring equipment. For this analysis, utility costs are assumed to be 0.

4.2.8 Residual Waste Shipping and Handling

The residual waste for both PWT systems are assumed to be spent substrate and treatment and settling pond sludge. This analysis assumes that substrate will require removal and replacement once every 5 years for both systems. It is assumed that spent substrate will be dewatered on site and disposed of at a recycling facility or landfill. Substrate removal and replacement and pond sludge removal costs for both systems are covered in Section 4.2.10, maintenance and modifications. The total cost for pond sludge and substrate disposal for the SAPS system is estimated to be $20,100 over a 15-year period. The total cost for pond sludge and substrate disposal for the Aquafix system is estimated to be $52,400 over a 15-year period. Costs for residual waste shipping and handling are based solely on substrate volume. Costs for different sized treatment and settling ponds are proportional to the baseline system.

4.2.9 Analytical Services

Analytical costs associated with either PWT system include laboratory analysis, data reduction and tabulation, quality assurance/quality control (QA/QC), and reporting. For each system, this analysis assumes that one influent sample and two effluent samples will be collected once a month and that two substrate and sludge samples from each pond will be collected quarterly. The pond sludge samples will be analyzed for total metals, and substrate samples evaluated for microbial activity. Influent and effluent samples will be analyzed for total metals, alkalinity, anions, TSS, and pH. Monthly laboratory analysis will cost about $1,170, and quarterly substrate and pond sludge analysis will cost about $2,920 per year. Data reduction, tabulation, QA/QC, and reporting are estimated to cost about $4,660 per year. Total annual analytical services for each system are estimated to cost about $21,620 per year and $324,300 over a 15-year period.

4.2.10 Maintenance and Modifications

Total costs for maintenance and modifications over a 15-year period for the SAPS and Aquafix systems including repair and maintenance, pond sludge removal, and substrate removal and replacement is estimated to be $67,600 (SAPS) and $71,200 (Aquafix), respectively. No modification costs are assumed to be incurred. The removal and replacement cost will vary proportionally with the treatment and settling pond size.

4.2.11 Demobilization

Site demobilization costs for either system include excavation of the substrate and concrete vaults and weirs, disposal of substrate, pond sludge removal, and backfilling the ponds. Costs for backfilling of the ponds is based on the assumption that native material from the original wetland excavation was left on site. The total demobilization cost is estimated to be $27,100 for the SAPS system and $60,400 for the Aquafix system. This cost will vary proportionally with treatment and settling pond size.

5
Technology Status

About 200 Aquafix units of various sizes and configurations are currently treating AMD in the United States. The effectiveness of these systems has been reviewed by Mine Safety Engineering (MSE), and was discussed in several publications, including Skousen and Jenkins 1993, and "The Proceedings of Fourteenth Annual West Virginia Surface Mine Drainage Task Force Symposium" (Jenkins and Skousen 1993).

SAPS technology has been in the public domain for many years and has been used in various locations in the midwestern and eastern U.S. The effectiveness of this technology has been discussed in several publications, including Kepler and McCleary 1994 and Watzlaf 1997.

In addition, PWT systems have been constructed and tested or are being tested by EPA, various state agencies, and industry. In Colorado, the State's Division of Minerals and Geology has constructed several PWT systems to treat AMD. These PWT technologies were also being considered, but not selected, for sources of contaminated water located in remote portions of the Summitville site where it would otherwise be difficult to direct flow into the active treatment plant.

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