RECLAMATION
Managing Water in the West

Streamlined Remedy Assessment
Barite Hill Pit
Barite Hill Mine
McCormick, South Carolina

Prepared For: EPA Region 4
Atlanta, Georgia

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
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Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Table of Contents

Streamlined Remedy Assessment
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Executive Summary

This report presents a streamlined remedy assessment for removal actions at an acid pit at the Barite Hill Mine. The Barite Hill Mine is an abandoned open pit gold mine located three miles south of McCormick, South Carolina. It was operated as a surface mine with cyanide heap-leaching for gold recovery from 1991 until 1995 when mine reclamation was initiated. The company, Nevada Goldfields, suspended site reclamation activities when they filed for Chapter 7 bankruptcy in 1999 leaving portions of the mine reclamation and closure activities uncompleted. In addition to the unfinished work, environmental issues are manifesting at the site. The main problem is the generation of sulfuric acid from the waste rock and spent ore. The gold ore, and most of the waste rock, contains significant amounts of the iron sulfide mineral pyrite which is the source of acid rock drainage at the mine.

At the request of the EPA Region 4 Emergency Response and Removal Branch, personnel from the Bureau of Reclamation conducted an onsite assessment during the period March 27 through 29, 2007. This work was performed as part of a Removal Site Evaluation of the 795-acre site. The assessment identified the acidic Barite Hill Pit as the principal area of concern (Gobla, 2007). The other concerns are the evidence of trespassing at the property which does not have adequate warning signs nor complete perimeter fencing, and the presence of elevated cyanide concentrations in water contained within the leak detection sump at the Permanent Heap Leach Pad Pregnant Pond. The provision of additional fencing, signage, and deactivation of the cyanide are obvious remedies for the trespass problem and will be implemented as a part of any remedy option taken at the Site. The remedy for the Barite Hill Pit is a more complex issue and is the subject of this Streamlined Remedy Assessment.

The Barite Hill Pit is bounded on three sides by steep rock highwalls and contains an approximately 80-foot-deep lake of metal-laden acid water. A haul road provides access from the west side past piles of mine waste and an unstable overhanging rock ledge down to the waters edge. This pit presents both physical safety hazards and environmental hazards. The physical safety issues include the potential for people to fall from unstable mine highwalls, potential for crushing by falling rocks, and the potential for drowning in the lake which has formed in the pit. From an environmental perspective, the water in the pit is very acidic (typical pH measurements of the pit water are in the range of 1.5 to 2.2 standard units). The principal source of the acid is an estimated 250,000 cubic yards of pyrite-containing waste rock. Most of this waste rock lies on the west side of the pit where it is exposed to precipitation and storm-water runoff which subsequently drains into the adjacent pit lake. The acid water in the lake is seeping out of the pit and making its way to an unnamed tributary of Hawe Creek. The acid seepage has turned the creek

flow brown and stained the rocks with iron hydroxide precipitates. It has killed a one mile segment of the stream and is depositing heavy metals into beaver dams located downstream of the site. The beaver ponds are not engineered structures. Should the beaver ponds fail in response to a flood event, the metals-contaminated sediments will be transported to and impact Strom Thurmond Lake.

A more significant environmental hazard exists in the form of the potential for a sudden uncontrolled release of acid water from the Barite Hill Pit. In March 2007, the pit lake appeared to be less than 20 feet below the lowest point along the perimeter of the pit. The low point, a highwall located on the north side is acting as a dam between the pit lake and the adjacent creek. This highwall has not been engineered as a dam. The upper part of the highwall is comprised of a narrow berm of soil and weathered bedrock. Should the lake level rise to an elevation where it would spill over this rim there would be a failure caused by overtopping and rapid erosion. The failure is likely to suddenly release approximately 40 to 60 acre-feet of the acid reservoir in a catastrophic manner. The acid flood water would flow to and impact Strom Thurmond Lake located 4 miles downstream of the pit.

Mitigation of the acid pit lake at Barite Hill can be accomplished by one or more of the following remedy options:

1. No action, accept the consequences of the acid pit lake.
2. Construct spillway and fencing.
3. Perpetual water treatment.
4. Neutralize, backfill, and reclaim.
5. Blast the pit rim, partially backfill, and reclaim as a dry basin.
6. Minimal waste backfill, neutralize, and reclaim.

The findings of this Streamlined Remedy Assessment are that options 1, 2, and 3 are not sufficient to mitigate the problem because a hazardous acid and heavy metals bearing pit lake would remain at the site. Option 1, the no action alternative, is also not acceptable because the danger of a catastrophic release of acid water would remain if the pit rim were to fail. Option 2 would prevent a catastrophic release of acid water, but there would still be significant impacts to downstream receptors. A 1” rainfall would cause an estimated 500,000 gallons of acid water to flow out of the pit and into the downstream environment. Eventually the downstream beaver ponds will be poisoned and the acid impacts will be felt at Strom Thurmond Lake which is a recreational facility and drinking water reservoir. Option 3 for perpetual water treatment would eliminate the risk of offsite discharge (provided a large enough plant was built and kept operational) but there are implementation problems related to technology for treating such low pH water, available space for long term sludge storage, and the significant recurring costs to operate and maintain a sophisticated water treatment plant in perpetuity.

Remedy options 4, 5, and 6 are likely to provide a reclaimed pit which would have neutral drainage and are expected to be sufficient to mitigate the problem. The three options vary significantly in cost and complexity. Each of these options require neutralization/treatment of the existing acid water in the pit, involve some degree of lime amending and backfilling of mine waste rock, covering/capping of pyritic bedrock and mine waste exposures, and revegetation. The water in the pit would be neutralized and then discharged to the creek under Options 4 and 5. Under Option 6 the water would be neutralized but not discharged, a neutral pit lake would remain.

Option 4 has the advantage that in addition to eliminating the pit lake, all of the pyritic highwall exposures would be covered with fill. This option, which would completely backfill the pit, is a very high cost remedy because of the large volume of costly backfill that would be required. There is no clean backfill source of sufficient quantity available at the mine site. The backfill either would be acidic waste rock from the site, much of which would need to be neutralized, or clean backfill imported to the site.

Although feasible, Option 5 would require a significant level of site investigation and engineering design, and is expected to be costly to implement. To establish a free draining pit with minimal backfill requirements, part of the north highwall between the pit and the creek would be blasted and removed. The water table in the pit would be lowered to be similar to that of the adjacent creek. As a result of eliminating the pit lake, the hydraulic gradient in the remaining pyritic highwalls would increase and much of these highwalls may remain uncovered. Extensive grouting to prevent a network of acid seeps from establishing within the remaining highwalls would be required. Like Option 4, a significant portion of the backfill would either need to be neutralized acid waste rock or imported clean fill. The part of the pit below creek level would be filled with sludge from neutralization and it may be difficult to backfill into or over this sludge to establish a free draining surface that can be stabilized and reclaimed.

Option 6 (minimal waste backfill, neutralize, and reclaim) is recommended for implementation. This option has a moderate cost and is of medium complexity to implement. Under this option the pit lake would be neutralized but the lake would remain. A spillway would be constructed to allow neutral water to overflow to the creek. A small amount of the mine waste on the west side of the pit would be pushed into the lake, and the remaining waste backfill and most of the adjacent bedrock exposures would be capped and reclaimed. Some of the pyritic highwalls would be capped while others, which are too steep to cover, would remain exposed to the environment. Because the pit may continue to generate small amounts of acid, carbon loading will be performed to establish a sulfate reducing bacteria system in the pit. The pit lake will be monitored. The water quality would be controlled by the infrequent addition of lime and or carbon to maintain near neutral conditions.

None of these options are a perfect solution to the problem, the wet climate, geometry of the site, and pervasive presence of pyrite is such that the risk of a small amount of residual seepage exists for even the most costly and complex options. Option 6 has a significantly lower cost than options 4 or 5, will take less time to implement, and is likely to provide a similar level of protection to that of the other options. The actions under Option 6 are not irreversible. They would not preclude the later implementation of one of the other options if necessary. Option 6 is recommended as the preferred option.

INTRODUCTION

This Streamlined Remedy Assessment report describes and evaluates six options for mitigation of priority environmental issues at the Barite Hill Mine in McCormick, South Carolina. The principal environmental problem at the abandoned gold mine is the Barite Hill Pit, an open-pit mine excavation which has also been referred to as the "Main Pit." This pit has formed a lake containing an estimated 65 million gallons of very acidic water.

The pit began filling with water after mining ended in October of 1994 and the resulting acid lake will eventually exceed 80 feet in depth. The north pit highwall area is a topographic low point along the perimeter of the pit. It will form a spill point when the pit level rises to near the top of the wall. In its current condition the upper part of the north wall consists of approximately 4 to 6 feet of soil and highly weathered rock overlying mineralized bedrock. The bedrock is fractured and acid seepage from the pit lake has been observed seeping through the wall to the adjacent creek. This seepage has sterilized the creek for a distance of a mile downstream. Although the wall is acting as a dam to contain the pit lake, it was not designed to be a dam. When the pit fills to overtopping the wall will fail and rapidly release an estimated 40 to 60 acre-feet of acid water.

The source of the acid is the pyrite contained in waste rock and in mineralized veins found in bedrock exposures. An estimated volume of 250,000 cubic yards of waste rock is present in and adjacent to the pit. Most of this waste (approximately 180,000 cubic yards) has been placed by the mining company as two separate backfills on the west side of the pit.

The Bureau of Reclamation previously prepared an inventory of site conditions based upon a field visit conducted during March 27, 28, and 29, 2007. For detailed descriptions of the various site features refer to the inventory report (Gobla, 2007). This report only describes the Barite Hill Pit in detail.

Location and Site Overview

The Barite Hill mine is located in a wooded area 3 miles south of McCormick, South Carolina. It is north of road 30 and lies between US highways 378 and 221. It lies on a northeast trending ridge above unnamed tributaries to Hawe Creek which are four miles upstream of Strom Thurmond Lake. Elevations vary from a high of approximately 510 feet at ridge tops to lows around 400 feet along the tributaries of Hawe Creek. The Barite Hill Pit was excavated to an elevation of 340 feet.

It was operated as a surface mine with cyanide heap-leaching for gold recovery beginning in 1991. Two open pit mine excavations were made at the site. The Rainsford Pit was a small open pit mine which was later backfilled with waste rock and capped. The Barite Hill Pit was excavated into a hilltop, the main part of the excavation covering about 10 acres of land. Mining in the Barite Hill Pit ended in October 1994. Leaching and processing of gold ore ended in 1995 when mine reclamation was initiated. The heap leach pads were rinsed to remove cyanide and were reclaimed. Process fluids in the process ponds were treated by operation of a water treatment plant. Waste rock facilities were also reclaimed by grading and capping with clay, topsoil, and vegetation. The company, Nevada Goldfields, suspended site reclamation when they entered into bankruptcy in 1999.

The permitted mine site totals 795.2 acres. Of this total, 659.7 acres were designated as buffer area (areas not disturbed beyond the pre-mine natural state); therefore the maximum disturbance area which was allowed under the mine permit was 135.5 acres. Most of the disturbance was reclaimed by the mining company. The current area of disturbance, not including the areas occupied by process ponds, is estimated to be in the range of between 20 to 25 acres. The disturbed areas are associated with the pit highwalls and benches, the clay borrow area, a sediment pond, the former topsoil stockpile area, and the site roads.

The water, sediments, and leak detection sumps at the process ponds were sampled and analyzed by others. Details regarding the ponds are presented in table 1. Only the leak detection sump at the Permanent Heap Pregnant Pond is of concern and requires mitigation. Other chemicals found at the site were removed during EPA's initial removal action.

Table 1. Process Ponds at the Barite Hill Mine

Pond Designation	pH measured on March 29, 2007	Storage Capacity in Gallons	Comments
Process Plant Pregnant Pond	9.30	1,370,000	60-mil HDPE liner with 20 mil PVC leak detection sump liner
Process Plant Barren Pond	9.10	690,000	60-mil HDPE liner
Process Plant Rinse Pond	9.08	690,000	60-mil HDPE liner
Process Plant Carbon Pond	9.20	Estimated 50,000	60-mil HDPE liner
Process Plant Contingency Pond	8.48	Estimated 4,400,000	Liner has been removed. Water seeps to diversion ditch.
Permanent Heap Pregnant Pond	7.20	1,500,000	30 mil PVC liner. Receives acid seepage from the Permanent Heap. High cyanide levels in the leak detection sump require mitigation.
Permanent Heap Barren Pond	8.10	5,500,000	It receives seepage flow from the Industrial Solid Waste Landfill.
Permanent Heap Rinse Pond	6.85	1,000,000	30 mil PVC liner. Largest acid seeps from Permanent Heap flow into this pond.

Climate

The site is located in a region of high precipitation. According to mine permit documentation (Water, Waste and Land, Inc., 1989), the annual average precipitation is 47 inches and annual evaporation is 46 inches. The wettest year on record is data from Clark Hill Dam which experienced 76.28 inches of precipitation. The storm water facilities at the mine were designed using a 100-year, 24-hour precipitation event of 8 inches.

Site Access

Access to the site is controlled by signage, fences and gates, and by natural barriers. The fencing is not complete. Although there are two locked gates along the site access road, the site is not completely closed to trespass. Local people have been using the site for recreation. Some rutting and erosion damage to the waste-rock caps built by the mining company has resulted from the use of off-road vehicles by trespassers. Additional fencing and warning signs need to be installed at the site.

Existing Roads

Existing roads at the site include the site access road which trends from the east to west across the site, the pit access roads, the permanent heap access road, the permanent heap process ponds access road. The access roads are shown in Figure 1.

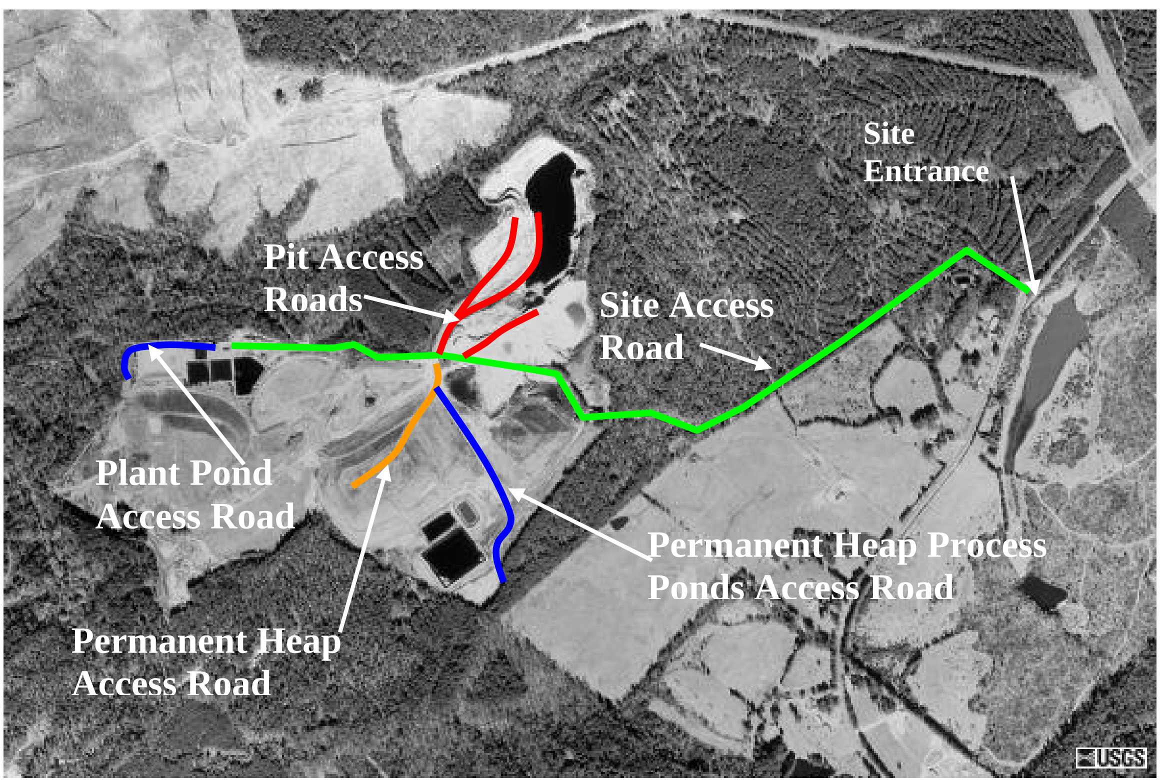

Figure 1. Aerial photograph of the Barite Hill Mine showing existing access roads.

GEOLOGY

Regional Geology

Barite Hill is the southernmost of four major surface gold mines which have been developed in the South Carolina Slate Belt. The other mines, located to the northeast, are Haile, Brewer, and Ridgeway. All of these mines have developed acid drainage problems due to the presence of pyrite in the ore and waste rock. The Ridgeway Mine has been the least problematic because the occurrence of pyrite at that mine is far less prevalent than that at the other mines.

The gold deposits at Barite Hill are hosted in igneous and metamorphic rocks which are locally called the "felsic pyroclastic sequence." The original sediments were altered and mineralized by igneous intrusions. All of the rocks were then altered by metamorphic action.

The mine area is one of moderate seismic activity. Slope stability analyses for the design of the mine facilities utilized a seismic coefficient of 0.05 g (Water, Waste and Land, Inc., 1989).

Local Geology

Host rocks for the Barite Hill deposit are sericitically-altered, felsic metavolcanic and metasedimentary rocks of the Late Proterozoic Persimmon Fork Formation, which consists of the Lincolnton metadacite and metarhyolite and the overlying lower and upper pyroclastic units. The rock types found at the mine include Lincolnton metadacite and metarhyolite, a quartz crystal porphyry with a finer-grained quartz-feldspar matrix. The Felsic metavolcanics are quartz and feldspar crystal tuffs with a quartz-sericite matrix. Intermediate volcanics are feldspar crystal tuffs with a chloritic matrix. The pyroclastic units include metasedimentary rocks which are mostly coarse to fine grained wackes. Outside the deposit are fine-grained mica schists, quartzite, and other metasedimentary rocks. Structurally the rocks strike approximately north 55 degrees east and dip 80 degrees to the northwest. Local bedding planes preserved in the metasediments strike north 45 degrees east with varying dips from near vertical to northwest dips. Contacts are steeply dipping.

The Barite Hill deposit is interpreted by Clark (1999) to be the result of Kuroko-type submarine volcanogenic base-metal sulfide mineralization followed by precious metal deposition under epithermal conditions. The Barite Hill deposit lies stratigraphically below an overturned contact between the upper and lower pyroclastic units. Gold-silver-rich zones in the Main Pit are partly coincident with lenses of siliceous barite rock, but not confined to them, and occur more commonly in pyrite-quartz altered fragmental rock. The four ore zones in the Main Pit are overlain by a zone of barite and base-metal enrichment, which is, in turn, overlain by a talc-tremolite alteration zone.

Mineralogy

The Barite Hill deposit was mined from 1990 to 1994. Approximately 1,835,000 grams (58,996 troy ounces) of gold and 3,390,280 grams (109,000 troy ounces) of silver were produced (Clark, 1999). Three stages of mineralization are recognized as 1) local base-metal sulfide, 2) early, gold-poor mineralization having abundant pyrite and base-metal sulfides, and 3) late, gold-rich mineralization. The gold occurs in quartz-pyrite veins and in volcanic rock fragments. The host rocks have been sheared and altered by the mineralizing events. Non-metallic minerals found at the site include quartz, feldspar minerals, barite, muscovite (the fine-grained variety called sericite), talc, and tremolite. The ore minerals are presented in Table 2:

Table 2. Ore minerals occurring at the Barite Hill Mine (Back and Clark, 1992).

Name	Chemical Formula
Gold	Au
Sylvanite	$(Au,Ag)Te_4$
Electrum	(Au,Ag)
Silver	Ag
Argentite	AgS
Galena	PbS
Hessite	Ag_2Te
Chalcopyrite	$CuFeS_2$
Chalcocite	Cu_2S
Bornite	Cu_5FeS_4
Covellite	CuS
Goldfieldite	$Cu_{10}Te_4S_{13}$
Tennantite	$Cu_{12}As_4S_{13}$
Atacamite	$Cu_2Cl(OH)_3$
Sphalerite	ZnS
Molybdenite	MoS_2
Unidentified bismuth and copper selenides	Various minerals containing Bi, Cu, and Se

In addition to the minerals listed in Table 2, it should be noted that other metallic elements are likely to be present. Minerals such as pyrite and sphalerite are known to be scavengers of other elements. During crystallization, scavenger minerals commonly incorporate small amounts of other elements as impurities in their crystal structure. The ore and waste rock may contain a large number of different metallic elements as a result of the impure nature of the minerals.

BARITE HILL PIT

Also called the “Main Pit” on drawings, this open pit mine excavation is bounded on three sides by steep rock highwalls and contains an approximately 80-foot-deep lake of metal-laden acid water. It was excavated from 1991 until mid-October 1994.

Figure 2. The most significant hazard remaining at the site is the Barite Hill Pit.

The pit occupies an area of approximately 20 acres. It consists of a 10-acre lake surrounded by 10-acres of disturbed uplands which drain towards the pit lake. The pit lake is continuing to grown in size. There are three access roads originating from the southwest side of the pit (Figure 1) which lead to 1) the upper northwest side of the pit, 2) down to the waters edge on the west side, and 3) along the top of the south highwall.

Although there are many rock types present, there appears to be two materials from a geochemical standpoint, oxidized soil and rock, and un-oxidized rock. The red-colored soil and rock is oxidized material (pyrite has been leached out over geologic time). The oxidized material has little potential to generate acid. This is evidenced by the fact that there is volunteer vegetation taking hold in the red soil and rock on the east side of the pit.

Figure 3. Photograph looking towards east side of the pit. The east highwall area shows signs of volunteer vegetation and it likely has a relatively low permeability. In the upper right part of the photograph, the excavation from the clay borrow area can bee seen which removed the top layer of red-colored clay soil.

Volunteer vegetation is not seen on the south side of the pit even though the soil and rock appears to be oxidized. The un-oxidized material is the grey- to yellow-colored rock which is rich in pyrite and is highly acid generating. This material is evident in the northeast, north and west sides of the pit highwalls (see Figure 4). Additionally, pyrite-containing waste rock has been dumped onto the gently sloped bench areas on the west side of the pit (see Figures 4, 5, and 6), and there are two major backfill zones on the west side of the pit. The backfill zones are filled with pyrite-containing waste rock which is a major acid source area draining into the pit.

Figure 4. View of grey-colored rocks rich in pyrite on the west side of the pit. The south backfill is seen in the lower left part of the photograph.

Figure 5. Photograph showing the disturbed area on the southwest side of the Barite Hill Pit. This is a major source area for acid water draining into the pit.

Figure 6. Close-up view of some of the pyrite-containing waste rock piles dumped onto the upper benches on the west side of the Barite Hill Pit.

Prior to leaving the site in 1999, the mining company took two actions to control acid in the pit area. The pit lake was amended with lime to neutralize it, and the waste piles were coated with "gunite" to prevent acid runoff from forming. Neither of the actions were a success. The pit re-acidified because it was only partially full and it continued to receive acid input from the following four sources:

- Release of stored acid salts from rubble and fractured rock walls upon saturation by rising pit lake water levels.
- Inflow of acid stormwater runoff from exposed pyritic bedrock, waste piles, and backfill zones in adjacent unsaturated upland areas as a result of precipitation and snowmelt events.
- Oxidation of pyrite rubble and fractured rock highwalls by interaction of the upper aerobic water layer with the pit shoreline and shallow submerged zone.
- Dissolution of pyrite in the anaerobic zone by Fe^{+3} ions to release acidity and Fe^{+2} ions into the pit lake (iron cycling)


Figure 7. Photograph of damaged "gunite" coating on pyrite-rich waste rock left exposed in the upper benches of the Barite Hill Pit. The coating is a failed attempt to mitigate the acid drainage originating from this waste rock.

The gunite, a calcium-carbonate-rich spray-applied coating on the waste rock piles, was not successful in preventing acid generation. The gunite coating could not penetrate into the fine-grained portion of the pyrite-rich waste where most of the acid is generated. Acid formation is proportional to surface area of pyrite exposed to moisture and oxygen. Also, the gunite coating has very little tensile strength and is porous. It is easily fractured and loosened by temperature extremes and freeze-thaw action. In time the gunite was fractured, loosened, and removed by the weather.

Subsequent to the field inventory work, the State of South Carolina, Department of Health and Environmental Control, sampled the Barite Hill Pit on July 3, 2007 and found the pH values varied from 2.42 at the surface to negative 3.9 at a depth of 4 feet. Similar negative pH water was measured at depths of 25 and 30 feet. This is the most acidic water ever reported in a natural or manmade body of water anywhere in the world. Prior to this, a pH reading of -2.47 taken inside the Richmond Adit at the Iron Mountain Mine Superfund Site in California was considered to be the world's most acidic water (Nordstrom and Alpers, 1999). The negative pH readings at Barite Hill were obtained the day after a significant rain storm which had been preceded by weeks of drought. It is thought that acid salts had evapo-concentrated in the uplands on the west side of the pit and were suddenly flushed into the pit lake by the storm.

Other sampling events of the Barite Hill Pit show pH values in the range of 1.5 to 2.2. It is thought that the negative pH values are being attenuated back to the 1.5 to 2.2 range by silicate buffering. Silicate buffering is the dissolution of silicate minerals such as clay, feldspar, and mica by very low pH water.

This pit presents both physical safety hazards and environmental hazards. The physical safety issues include the potential for people to fall from unstable mine highwalls, potential for crushing by falling rocks, and the potential for drowning in the lake which has formed in the pit.

From an environmental perspective, the acid water is seeping out of the north side of the pit and making its way to a tributary of Hawes Creek. The acid seep has turned the creek flow brown and stained the rocks with iron hydroxide precipitates. It has killed a one-mile segment of the stream and is depositing heavy metal sediments into beaver ponds below the impacted segment of the creek. The volume of seepage would be affected by the head differential between the pit lake and the creek. It is likely that the seepage rate has accelerated as the pit level continues to rise and that most of the downstream impacts have occurred in the past few years.

Pit Lake Overtopping

EPA has asked if the pit can fill to overtopping and what are the likely consequences. Some had argued that seepage outflows might offset the rise in the pit lake and result in a stable pit level that does not reach the rim of the pit. The following evaluation shows that unless there is a drought, the pit is expected to rise to overtopping levels within the next three to five years. If no action is taken, a catastrophic release of an estimated 20 million gallons of acid water is expected to occur.

Depending upon climatic and geologic conditions, a pit lake will either become a terminal lake (typical in a dry climate) or a flow through lake (typical in a wet climate). Pit lakes receive water input by three natural processes:

- Direct Precipitation
- Runoff from adjacent watersheds
- Groundwater inflow

Pit lakes loose water by two natural processes:

- Evaporation
- Groundwater outflow

The climate and water balance will determine if a pit becomes a terminal lake or a flow through lake. In the arid southwest states like Nevada and Arizona, pit lakes are typically terminal lakes. Evaporation rates exceed the rate of water inflow and as a result the water table does not fully recover after mining ends. Depression of the groundwater table is the long-term condition which results in a sustained groundwater inflow to the evaporating pit lake.

In wet climates such as in South Carolina, South Dakota, and Montana, pit lakes typically continue to fill until they become flow through lakes. The inflows from precipitation and runoff exceed the evaporative and seepage losses resulting in a mounding of the water table. These pits typically fill to the surface and have both groundwater and surface water discharge. In rare cases a flow through lake may loose all of its water to groundwater outflow if the upper walls of the pit are comprised of very pervious material.

The Barite Hill pit will become a flow through lake. Seepage from the pit to the unnamed tributary to Hawe Creek was recently estimated to be around 5 gpm. The upper pit walls, while allowing some acid seepage to flow to the adjacent creek, do not appear to be pervious enough to prevent the pit from filling completely. It is expected that the pit lake level will continue to rise until it begins to spill to surface flow pathways. This is consistent with the experiences at two other gold mines in South Carolina. At the Haile Mine (Champion and Snake Pits) and at the Ridgeway Mine (South Pit and North Pit), the pits are filling to the low side rim and will become flow through lakes. Although the Barite Hill site is currently experiencing drought conditions, this will only delay the filling and overtopping of the pit, not prevent it.

At Barite Hill the water level in the pit is believed to have been rising since the mining activity ceased in mid-October, 1994. It is presumed that the pit began filling as soon as mining ended. There would be no incentive to keep water out of the pit after all of the ore had been extracted. The aerial photograph shown in Figure 8, shows the pit lake as it appeared in the year 2000 which would have been 6 years after the end of mining. Also, water in the pit appears to have increased up to the present time. The approximate extent of the pit lake as it was observed in March 2007 has been added to the aerial photograph shown in Figure 8.

A water balance model does not exist for the Barite Hill pit. When the seepage outflows and evaporative losses are greater than the inflows from seepage, precipitation, and runoff, the pit lake will decrease in volume. When the inflows from seepage, precipitation, and runoff are greater than the losses from seepage outflow and evaporation the pit lake will increase in volume. Accurate data regarding groundwater seepage do not exist, but groundwater wells drilled by the mining company indicated that the bedrock is fairly tight. This is consistent with the low rate of seepage (5 gpm) of acid water coming from the pit to the receiving creek. What is known is that the pit lake now covers about 10 acres of the 20-acre pit watershed. In other words there is about 10 acres of uplands draining into the 10-acre pit lake. This site is in a wet climate. The mining company's consultants (Water, Waste and Land, Inc., 1989) reported that there is on average 47 inches of precipitation and 46 inches of evaporation per year, that the 100-year, 24-hour storm event is a precipitation of 8 inches, and that the wettest year on record is 76.28 inches of precipitation. A few years of wet weather is all that is needed to fill the pit ot overtopping. All of the other gold mine pits in South Carolina have become or will soon be flow through lakes, Barite Hill is following the same trend.

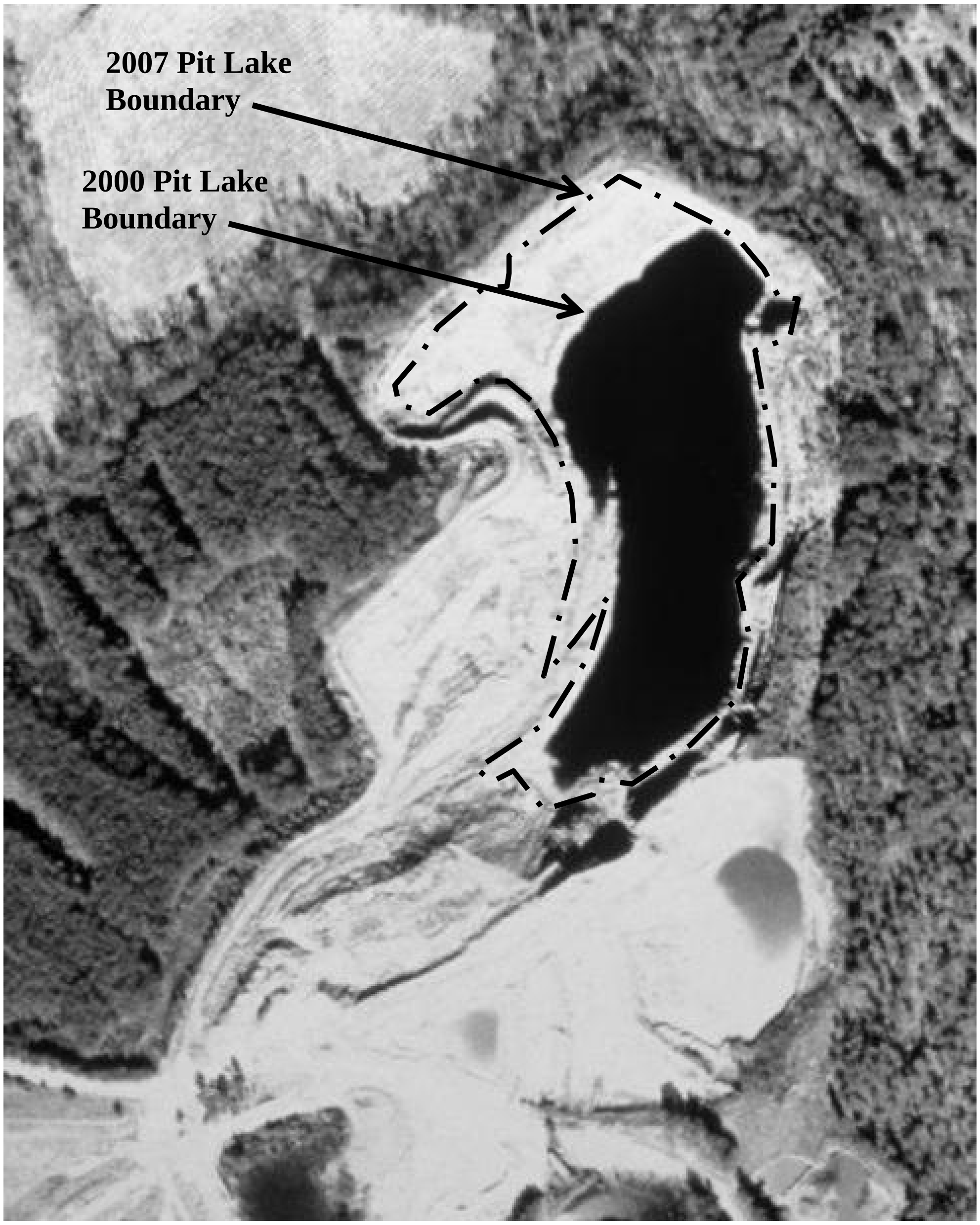

Figure 8. Aerial photograph of the Barite Hill Pit in the year 2000 showing the pit lake about 6 years after mining ended. The pit lake boundary in March 2007 (about 12 years after mining ended) has been drawn onto the image.

Figure 9. View of the north pit wall where outflow from the pit will eventually occur. The spill point is likely to be near the left side of the photograph.

It is concluded that the pit will fill to overtopping. Considering that there is only about 15 to 20 feet of freeboard left (see Figure 9), and that the upper 6 to 10 feet of the pit rim are comprised of soil and weathered bedrock, the pit could fill to dangerous levels in as little as 3 to 5 years time. Once the pit reaches the soil layer there is a very high risk of failure. The soil and weathered bedrock are not likely to be capable of performing as a dam. Prolonged seepage induced erosion could cause this soil layer to fail even before the water reached the overtopping elevation. If a seepage type of failure did not occur, then it is certain that it would fail upon overtopping; the soil rim can not stand up to the concentrated overtopping flow of water and would rapidly erode. Either type of failure would cause rapid erosion that would transition from down-cutting to a widening that would open a breach that would then discharge a flood of acid water in a catastrophic (uncontrolled) manner. It is estimated that at least 4 to 6 feet of the upper part of the pit lake would be released as a sudden outflow before the down-cutting reached a harder layer of rock which would slow and eventually stop the release. For the 10-acre lake, this would equate to a flood surge of between 40 to 60 acre-feet (13 million to 19.6 million gallons) of acid water.

Action to prevent a catastrophic release needs to be taken. At the very least, the loose soil and rock should be removed and a spillway structure needs to be constructed. If a spillway is provided, the pit is still expected to release acid water with each significant rain event. To provide some perspective on this, the amount of water released by a 1-inch rain from a full pit can be calculated. Assuming the pit lake is at the spillway level (about to overflow) a 1-inch rain event would input 271,000 gallons of water as precipitation onto the pit lake water surface and another 230,000 gallons as runoff (assuming 85% runoff) from the adjacent 10-acre watershed. This means that a 1" soaking rain is likely to push 500,000 gallons of highly acidic water through the pit and into the creek in a single event. An action like neutralizing the pit should also be considered for implementation.

Summary of Pit Conditions

In summary the Barite Hill Pit has the following characteristics:

1. The Barite Hill Pit is an open pit mine excavation occupying approximately 10-acres of land area. Around the perimeter of the pit is an adjacent watershed of another estimated 10 acres of land which drains into the pit. The adjacent watershed is comprised of undisturbed forest, bedrock exposures, and backfilled areas. The bedrock exposures forming the pit perimeter are comprised of "cliff like" highwalls and benches (flat areas). On the west side of the pit there are two separate zones of the former pit excavation which have been backfilled with waste rock taken from the deeper part of the open pit mine excavation. The backfill is up to 50 feet thick and extends down to the waterline. Piles of pyrite containing waste rock have also been dumped and scattered beyond the footprint of the two backfill zones.

2. A 10-acre pit lake has formed inside the mine excavation due to the accumulation of direct precipitation and runoff from the adjacent watershed. Testing on several occasions shows that the water in the pit typically has a pH of about 1.5 to 2.2 standard units. On July 3, 2007, one day after a heavy rain, the South Carolina Department of Health and Environmental Control measured pH values in the pit ranging from 2.42 to negative 3.98 standard units. These pH levels characterize the water in the pit as a Resource Conservation and Recovery Act hazardous waste. In addition, the acid in the pit is sulfuric acid which is a CERCLA listed hazardous substance. The acid water also contains large amounts of iron and sulfate along with significant levels of heavy metals including arsenic, cobalt, copper, lead, manganese, selenium, and zinc.

3. Acid water seepage through the highwall on the north side of the pit at an estimated rate of 5 gallons per minute has been observed entering an adjacent tributary of Hawe Creek. The seepage has negatively impacted the tributary for 1 mile with pH readings between 2 and 4 standard units being observed along the creek. Downstream of the impacted creek segment, beaver dams are assisting in capturing and buffering the acid drainage and are preventing further migration of the acid.

4. The acid pit has been filling up since its abandonment and is expected to eventually overflow into the adjacent tributary of Hawe Creek. This flow

would then drain to Strom Thurmond Lake, a recreational lake and drinking water reservoir located 4 miles downstream of the pit.

5. The overflow point for the pit would be along the north highwall which has the lowest crest elevation along the pit perimeter and is immediately adjacent to the creek lying a short distance further to the north. This “low side” highwall of the acid pit was not constructed to be a dam, but is serving as one. The upper 4 to 6 feet of the north highwall is comprised of disturbed soil overlying weathered bedrock In the event of a significant series of rain events causing the pit to overflow, it is likely the wall will experience a rapid erosion failure and will suddenly discharge as much as 40 to 60 acre-feet of acid water to the creek. Such an event would not only have significant impacts to biota in the creek, but would be expected to impact a portion of Strom Thurmond Lake as well.

6. The principal source of the acid is an estimated 250,000 cubic yards of pyrite-containing waste-rock rubble located around the perimeter of the pit which reacts with rainfall and storm-water runoff. The majority of this acid-generating waste-rock rubble is located on the west side of the pit in two masses of backfill estimated to have a volume of more than 180,000 cubic yards. A smaller acid source is identified as the pyrite-bearing veins which are present in bedrock exposures in the pit “cliff-like” highwalls.

REMEDY OPTIONS FOR THE BARITE HILL PIT

Mitigation of the acid pit lake at Barite Hill can be accomplished by one or more of the following remedy options:

1. No action, accept the consequences of the acid pit lake.
2. Construct spillway and fencing.
3. Perpetual water treatment.
4. Neutralize, backfill, and reclaim.
5. Blast the pit rim, partially backfill, and reclaim as a dry basin.
6. Minimal waste backfill, neutralize, and reclaim.

The options are described along with the estimated costs and expected performance of each remedy. It should be noted that engineering designs have not been prepared for the various remedy options. The costs are based upon conceptual level estimates of material quantities and major project components. The costs are preliminary in nature and are for the purpose of comparing one option to another. The costs are subject to change when more detailed engineering designs are prepared for the selected remedy option.

Option 1. No Action, Accept the Consequences of the Acid Pit Lake

This is the no action alternative. Under this option no actions would be taken, the site would be left in its present condition and the consequences of the long-term presence of the acid pit lake would be accepted. The acidic pit would remain as a threat to wildlife. Acid water would continue to seep out of the pit and degrade the tributary to Hawe Creek and eventually overwhelm the beaver dams. In a few years time the pit will fill to overtopping, and there will be a catastrophic release of 40 to 60 acre-feet of acid and metals-laden water which would impact Hawe Creek and Strom Thurmond Lake. This is not a viable alternative for Barite Hill because of the ongoing downstream degradation and the danger of a catastrophic release of acid water if the pit rim fails.

Option 2. Construct Spillway and Fencing

At a minimum the low pit wall must be stabilized by construction of a spillway to prevent a catastrophic release. The upper part of the ridge forming the low end of the pit would be excavated to remove the loose soil ridge and weathered rock to eliminate the potential for a catastrophic release of water from the pit lake. The remaining rock would be evaluated for its durability, if necessary the rock would be grouted. A spillway capable of handling a large flood would be installed in a notch cut into the rock and an energy dissipation feature (plunge pool) would be installed in the creek bed below the spillway. Site perimeter fencing and signage would be installed to discourage trespass access. Costs for this option are presented in Table 3.

Table 3. Estimated Implementation Costs for Option 2

Construction Component	Estimated Cost to Construct
Drill, blast, and excavate spillway notch, chute, and plunge pool	$100,000.
Install 30 foot wide reinforced concrete spillway	$100,000.
Furnish and place riprap for spillway chute and stream plunge pool. Riprap at $30/yd^3$	$50,000.
Grouting rock below spillway if required	$50,000.
Total Cost for Option 2	**$300,000.**

Option 2 would eliminate the risk of a catastrophic release of more than 40 acre-feet of acid water. The pit will still fill to overflowing in a few years time and the receiving creek will continue to experience continuous acid seepage. The spillway would overflow Fish kills in Strom Thurmond Lake would still be a likely outcome after large precipitation events. A 1" rain would cause 500,000 gallons of acid water to flow out of the pit.

Option 3. Perpetual Water Treatment

Perpetual water treatment would be performed to maintain the pit lake at a level below the current pit rim and prevent acid releases. Grouting of the north side of the pit, or a major drawdown of the existing pit level would be necessary to eliminate the acid seepage to the creek. Because of the very acidic nature of the pit water (pH 1.5 to 2 with occasional inflows of negative pH water), off-the-shelf semi-passive lime addition systems are not likely to be effective. A conventional water treatment plant with an estimated 250 to 300 gpm capacity would be needed to deal with storm surges and unusually wet years to keep the pit lake level drawn down. In an average year the plant would operate at around 100 gpm. The highly acid nature of the site water would generate large volumes of sludge. Sludge storage and disposal would become a significant cost issue in the long term. Also, because of the presence of selenium, it is possible that an additional treatment train, such as a reverse osmosis system, for selenium removal would be required. The plant construction costs are estimated in Table 4.

Table 4. Estimated Implementation Costs for Option 3

Construction Component	Estimated Cost to Construct
Establish electric power line into the site	$30,000.
Pumping system to transfer water from pit to water treatment plant.	$100,000.
Construct pipelines for sludge disposal and clean water discharge.	$50,000.
Construct 300 gpm lime neutralization water treatment plant	$3,000,000.
Sludge thickener for high sulfate water	$1,000,000.
Embankment for sludge disposal at clay borrow pit	$20,000.
Construct optional treatment train for selenium removal	$1,500,000.
Total Cost for Option 3	**$5,700,000.**

Ongoing treatment costs would be substantial to maintain a full time presence at the site to operate the treatment and sludge disposal facilities ($1 million/year cost range). There would always be an acid lake at the site which is a hazard to wildlife. This option is not recommended for further consideration due to the high long-term operation and maintenance costs and the continual presence of a very acidic pit lake.

Option 4. Neutralize, Backfill, and Reclaim

The acid pit lake would be neutralized, discharged to the creek, and then an estimated 1.15 million cubic yards of waste would be hauled in to fill the pit to the level of the low north rim thus eliminating the pit lake. The volume of fill is a rough estimate because current topography of the final pit excavation does not exist which would allow a more accurate volume to be computed. The fill would also rise to cover the sulfide bedrock exposures on the west and north sides of the pit, and a low permeability soil cap would be placed over the backfill. A growth layer of soil would be added and the surface would be amended with organic material and seeded. The spent ore in the Heap Leach Pad and the Solid Waste Disposal Landfill is probably not acceptable for use as backfill material due to its ongoing release of selenium. Waste Area A is the default source of the fill. This fill would need to be lime amended.

Table 5. Estimated Implementation Costs for Option 4

Construction Component	Estimated Cost to Construct
Lime for pit lake neutralization	$250,000.
Lime mixing and slurry pumping station	$200,000.
Reestablish access to Waste Repository A. Clear, grub, and strip 5 acres at $10,000 per acre	$50,000.
Amend 220,000 cubic yards of waste rock for present acidity at 0.062 tons of limestone per yd^3 at $90/ton.	$1,230,000.
Excavate, haul, and place amended waste rock below creek level. 220,000 yd^3 at $7.00/ yd^3.	$1,540,000.
Amend 930,000 cubic yards of waste rock for present and future acidity at 0.12 tons of limestone per yd^3 at $90/ton.	$10,000,000.
Excavate, haul, and place amended waste rock above the water table 930,000 yd^3 at $7.00/ yd^3.	$6,510,000.
Clear, grub, and strip 7 acres for clay borrow area	$70,000.
Excavate, haul, place, and compact 2 ft thick clay cap over 15 acres. 48,500 yd^3 at $15.00/ yd^3.	$730,000.
Excavate, haul, place, and amend 1.5 ft thick layer of growth medium over 15 acres. 36,300 yd^3 at $25.00/ yd^3.	$980,000.
Fertilize, seed, and mulch 15 acres. $10,000. per acre	$150,000.
Total Cost for Option 4	**$21,710,000.**

This option has a high construction cost because of the requirements to transport a large amount of material and needs for extensive amounts of lime for fill neutralization. Although clean fill might be imported to the site, a source would need to be identified and it might have similar costs depending upon the haul distance and purchase price. The backfill would be capped with 2 feet of clay and 1 foot of growth medium and then be revegetated. A small amount of acid seepage to the creek is likely to continue since the north pit wall would remain as a source, although this could be corrected by an extensive grouting operation. This option would have the highest capital construction costs but minimal long-term costs.

Option 5. Blast the Pit Rim, Partially Backfill, and Reclaim as a Dry Basin

The acid pit lake would be neutralized, discharged to the creek, and then the north wall would be drilled, blasted, and excavated down to near the creek level (about elevation 400). The portion of the pit below the creek level would be filled with the blasted material to eliminate any remaining part of the lake. This waste would need to be heavily lime amended to account for existing and future acid generating potential. The waste piles deposited in the adjacent 10-acre area on the west side of the pit would be shaped and capped. Steep pyrite-containing highwalls on the west side of the pit either would be grouted, blasted and covered with clay, or covered with amended backfill to prevent acid generation. Any rock blasted for highwall reduction would also require either deep burial or shallow burial with full lime amendment and capping. After the pit shaping and filling was completed, a low permeability clay soil to form a cap. A layer of growth soil would be placed and heavily amended with organic material. This would then be seeded and the result would be a free draining pit with clean runoff. A storm-drainage channel with rock armoring would be placed in the main drainage pathway through the reclaimed pit and some small wet boggy areas may be present in the bottom of the pit. This option is similar to that originally proposed by the mining company's consultants and was permitted by the State of South Carolina. Current pit topography is not available to precisely evaluate the quantities of materials to be blasted and to evaluate the volume of the pit floor below the creek level to be filled.

This option has the excellent chances for success with little to no acid seepage reporting to the creek. It would eliminate the pit lake and provide clean vegetated surfaces for surface water runoff. In time a stable forested surface would be established. The construction costs are less than option 4 but more than option 6.

Table 6. Estimated Implementation Costs for Option 5

Construction Component	Estimated Cost to Construct
Lime for pit lake neutralization	\$250,000.
Lime mixing and slurry pumping station	\$200,000.
Drill, blast, and excavate 300 feet along north wall to create a free draining pit. 330,000 yd^3 at \$ 12/yd^3.	\$3,960,000.
Drill, blast, and excavate to reduce slope of pyritic highwalls on west side of pit. 60,000 yd^3 at \$ 12/yd^3.	\$720,000.
Grouting highwall exposures on the northeast and northwest sides of the pit.	\$1,000,000.
Amend 390,000 yd^3 waste rock with limestone at 0.12 tons of limestone per yd^3 at \$90/ton.	\$4,210,000.
Clear, grub, and strip 7 acres for clay borrow area	\$70,000.
Excavate, haul, place, and compact 2 ft thick clay cap over 15 acres. 48,500 yd^3 at \$15.00/ yd^3.	\$730,000.
Excavate, haul, place, and amend 1.5 ft thick layer of growth medium over 15 acres. 36,300 yd^3 at \$25.00/ yd^3.	\$980,000.
Fertilize, seed, and mulch 15 acres. \$10,000. per acre	\$150,000.
Furnish and place 4,000 yd^3 riprap for drainage channel through reclaimed pit. Riprap at \$30/yd^3	\$120,000.
Total Cost for Option 5	**\$12,390,000.**

Option 6. Minimal Waste Backfill, Lime Neutralization, and Carbon Addition

An estimated 50,000 cubic yards of pyrite waste in the adjacent 10-acre disturbed area would be pushed into the deep part of the pit to reduce the slope of the two backfill zones leading down to the water. The pit lake would be neutralized and the upper 10 feet of the lake may need to be discharged to facilitate reclamation of the final littoral zone (shoreline area) of the lake. Exposed pyrite containing highwalls would be evaluated for blasting, grouting, or backfilling to eliminate this acid source at and above the final water level of the lake. A spillway would be constructed to prevent failure of the north wall of the pit, and to help establish a relatively stable pit lake water surface elevation. The spillway would include a concrete overflow weir structure. Grouting of the surrounding rock to minimize seepage and strengthen the rock for anchoring the spillway may be required and depends upon an assessment once the rock is exposed. The disturbed area to the west of the pit and the reduced rock and mine waste slopes to remain above the water line would be covered with lime, clay soil, and growth medium. The reshaped backfill zones would also be covered with a geomembrane. Growth medium would be amended with organic material and would be seeded. Organic carbon would be added to the pit to establish a sulfate reducing bacteria treatment zone to mitigate remaining acid sources.

Table 7 Estimated Implementation Costs for Option 6

Construction Component	Estimated Cost to Construct
Lime for pit lake neutralization	$250,000.
Lime mixing and slurry pumping station	$200,000.
Carbon loading for acid pit	$250,000.
Drill, blast, and excavate spillway notch, chute, and plunge pool	$100,000.
Install 30 foot wide reinforced concrete spillway weir crest.	$100,000.
Furnish and place riprap for spillway chute and stream plunge pool. Riprap at $30/yd^3$	$50,000.
Grouting rock below spillway if required	$50,000.
Blasting to reduce rock ridge between existing backfill zones.	$100,000.
Dozer grading to eliminate ponding, shrink waste footprint, and reduce slopes of existing pit backfill zones. 100,000 yd^3 at $15.00/ yd^3.	$600,000.
Clear, grub, and strip 3 acres for clay borrow area	$30,000.
Excavate, haul, place, and compact 2 ft thick clay cap over 6 acres. 20000 yd^3 at $15.00/ yd^3.	$300,000.
Excavate, haul, place, and amend 1.5 ft thick layer of growth medium over 6 acres. 15,000 yd^3 at $25.00/ yd^3.	$275,000.
Fertilize, seed, and mulch 6 acres. $10,000. per acre	$90,000.
Furnish and place riprap for shoreline and drainage ditch erosion control. 3,300 yd^3 at $30/ yd^3.	$100,000.
Shape and restore borrow area including fertilizing and seeding of 7 acres at $15,000/acre	$105,000.
Total Cost for Option 6	**$2,600,000.**

This option eliminates the acid pit and replaces it with an initially alkaline pH lake that in time will move to near neutral pH conditions. The carbon addition will in time reduce the metals and sulfate levels in the water. Long term maintenance would be minimal and would entail pH monitoring and occasional minor additions of lime and or organic material. This option is estimated to cost approximately $3 million. Option 6 is the favored option. It has moderate costs compared to options 4 and 5 and does not preclude the other options from being implemented if performance is not fully satisfactory. In fact, both options 4 and 5 would utilize the actions taken under this option as a first step, therefore this could be implemented and the site further studied for remedial action if necessary. Only the spillway construction would be an unnecessary expense if options 4 or 5 were later chosen. Option 6 is the favored option for a response at Barite Hill Mine and should be implemented.

Conclusions and Recommendations

The findings of this Streamlined Remedy Assessment are that options 1, 2, and 3 are not sufficient to mitigate the problem because a hazardous acid and heavy metals bearing pit lake would remain at the site. Option 1, the no action alternative, is also not acceptable because the danger of a catastrophic release of acid water would remain if the pit rim were to fail. Option 2 would prevent a catastrophic release of acid water, but there would still be significant impacts to downstream receptors. A 1" rainfall would cause an estimated 500,000 gallons of acid water to flow out of the pit and into the downstream environment. Eventually the downstream beaver ponds will be poisoned and the acid impacts will be felt at Strom Thurmond Lake which is a recreational facility and drinking water reservoir. Option 3 for perpetual water treatment would eliminate the risk of offsite discharge (provided a large enough plant was built and kept operational) but there are implementation problems related to technology for treating such low pH water, available space for long term sludge storage, and the significant recurring costs to operate and maintain a sophisticated water treatment plant in perpetuity.

Remedy options 4, 5, and 6 are likely to provide a reclaimed pit which would have neutral drainage and are expected to be sufficient to mitigate the problem. The three options vary significantly in cost and complexity. Each of these options require neutralization/treatment of the existing acid water in the pit, involve some degree of lime amending and backfilling of mine waste rock, covering/capping of pyritic bedrock and mine waste exposures, and revegetation. The water in the pit would be neutralized and then discharged to the creek under Options 4 and 5. Under Option 6 the water would be neutralized but not discharged, a neutral pit lake would remain.

Option 4 has the advantage that in addition to eliminating the pit lake, all of the pyritic highwall exposures would be covered with fill. This option, which would completely backfill the pit, is a very high cost remedy because of the large volume of costly backfill that would be required. There is no clean backfill source of sufficient quantity available at the mine site. The backfill either would be acidic waste rock from the site, much of which would need to be neutralized, or clean backfill imported to the site.

Although feasible, Option 5 would require a significant level of site investigation and engineering design, and is expected to be costly to implement. To establish a free draining pit with minimal backfill requirements, part of the north highwall between the pit and the creek would be blasted and removed. The water table in the pit would be lowered to be similar to that of the adjacent creek. As a result of eliminating the pit lake, the hydraulic gradient in the remaining pyritic highwalls would increase and much of these highwalls may remain uncovered. Extensive grouting to prevent a network of acid seeps from establishing within the remaining highwalls would be required. Like Option 4, a significant portion of the backfill would either need to be neutralized acid waste rock or imported clean fill. The part of the pit below creek level would be filled with sludge from neutralization and it may be difficult to backfill into or over this sludge to establish a free draining surface that can be stabilized and reclaimed.

Option 6 (minimal waste backfill, neutralize, and reclaim) is recommended for implementation. This option has a moderate cost and is of medium complexity to implement. Under this option the pit lake would be neutralized but the lake would remain. A spillway would be constructed to allow neutral water to overflow to the creek. A small amount of the mine waste on the west side of the pit would be pushed into the lake, and the remaining waste backfill and most of the adjacent bedrock exposures would be capped and reclaimed. Some of the pyritic highwalls would be capped while others, which are too steep to cover, would remain exposed to the environment. Because the pit may continue to generate small amounts of acid, carbon loading to establish a sulfate reducing bacteria system in the pit will be performed. The pit lake will be monitored. The water quality would be controlled by the infrequent addition of lime and or carbon to maintain near neutral conditions.

None of these options are a perfect solution to the problem, the wet climate, geometry of the site, and pervasive presence of pyrite is such that the risk of a small amount of residual seepage exists for even the most costly and complex options. Option 6 has a significantly lower cost than options 4 or 5, will take less time to implement, and is likely to provide a similar level of protection to that of the other options. The actions under Option 6 are not irreversible. They would not preclude the later implementation of one of the other options if necessary. Option 6 is the recommended as the preferred option.

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