SURFACE MINE POOL RECLAMATION WITH DIRECT ASH PLACEMENT[1]

Caroline M. Loop[2], Barry E. Scheetz, and William B. White

Abstract. A demonstration project has been put in place to evaluate the effect of ash placement in an acid mine pool. The surface mine pool, initially 510 million liters, is a remnant of pre-WWII mining of the Mammoth vein in the Eastern Middle anthracite field of Pennsylvania. Fly and bottom ash are placed at the face of two ash platforms in 32 Mg loads and later pushed into the mine pool with bulldozers. Natural compaction of the ash provides a load-bearing capacity of greater than 69 MPa, which is sufficient to permit trucks and bulldozers on the ash platforms. Once subaqueous deposition has been completed, the FBC ash will be covered with four feet of soil and seeded.

The pH value of the mine pool increased from 3.6 to 12.1 following ash placement. Calcite now precipitates from the top few feet of the water surface. The alkaline water has caused the precipitation of metals typically associated with acid mine drainage. Water samples collected from two test borings in the ash platform show a chemical signature very close to that of the surface mine pool. Despite the dramatic and homogeneous change in surface mine pool chemistry, no effect has been observed in any of the monitoring wells or at the outflow point of the basin.

Additional Key Words: culm, FBC, acid mine drainage, chemistry, anthracite.

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Introduction

Abandoned mine lands containing open water-filled pits, highwalls, and acidic mine water can be found throughout the anthracite region of Pennsylvania. While some of these areas are in the process of being reclaimed, others pre-date the Surface Mining Control and Reclamation Act (SMRCA) of 1977, and there exist little financial resources or incentive for their remediation under the current budgetary and regulatory conditions. By closely studying the effects of the placement of fly and bottom ash in an open surface mine pool, data are being gathered to evaluate the potential for the utilization of by-products to address the financial and environmental dilemma of subaqueous mine land restoration.

In 1978, the United States government passed The Public Utility Regulatory Policies Act (PURPA) requiring utilities to buy power from facilities using a waste material or renewable resource for fuel. PURPA, as well as new combustion technology for more efficient burning of waste anthracite (culm), made culm burning co-generation plants an economically viable option. In Pennsylvania, eight culm-burning co-generation plants have been constructed in the anthracite region. The plants all produce fluidized bed combustion (FBC) ash, which is rich in active alkaline material. Northeastern Power Company (NEPCO) is a co-generation facility, burning culm from local mine sites and supporting a greenhouse with residual heat (Fig. 1). Between 1989 and 1997, NEPCO's fly and bottom ash were used for land reclamation. It was placed at least 1.2 m (4 ft) above the perched water table and 2.4 m (8 ft) above the regional water table, as required by state law.

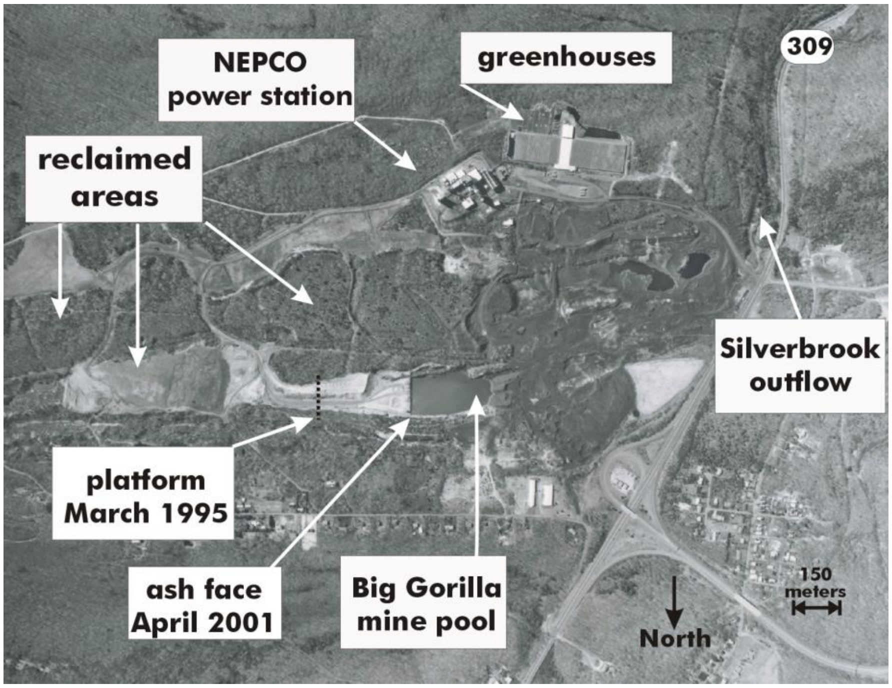


Figure 1. Aerial photo of Northeastern Power Company and the Silverbrook Basin, April 2001.

The Ellen Gowan project was a small-scale demonstration to evaluate the efficacy of placing ash in water (R. Hornberger, pers. com.). In 1997, following the Ellen Gowan's successful completion, the regional mining office of the Pennsylvania Department of Environmental Protection (PA DEP) in Pottsville, in conjunction with the Wilkes-Barre regional mining office, issued three demonstration permits to allow the placement of fly and bottom ash below the water table. The Shen Penn pit is the approved location for the "wet to wet" demonstration where an ash slurry will be pumped into a 73 m (240 ft) deep surface mine pool. At the Knickerbocker pit, an ash slurry has been pumped into a dry pit, and the water re-circulated for re-use in the slurry. The Knickerbocker pit represents the "wet to dry" component of the permits. A surface mine pool, initially 510 million liters (135 million gallons), and called the Big Gorilla, is located on NEPCO's property and represents the "dry to wet" demonstration. Fly and bottom ash are sprayed with water (conditioned) to minimize dust and maximize flow into the surface mine pool. The ash is then placed on two platforms, which extend further across the surface mine pool with time. Before the permits were issued, NEPCO had planned on filling the entire pit with clean fill from onsite. However, the quantities needed for placing the fill 1.2 m (4 ft) above the water level were difficult to find, and the process of moving them into the mine pool was prohibitively expensive.

Prior to 1997, clean fill was placed into the eastern end of the Big Gorilla mine pool, and extended above the water level. In August 1997, NEPCO began placing ash on this platform of clean fill. From the platform, the ash was introduced into the standing water of the surface mine pool in a manner that would minimize turbulent mixing of the ash and water. This paper reports on both structural and chemical effects of the ash placement in the Big Gorilla mine pool.

Geology

NEPCO is located in the Silverbrook Basin of the Eastern Middle anthracite field of Pennsylvania (Fig. 2). In this region, the Pennsylvanian strata are highly folded and contain significant thrust faults, remnants of the Alleghenian orogeny. The two major coal seams in the Silverbrook Basin are the Buck Mountain and the Mammoth, which are separated by 30-110 m (100-350 ft) of sandstone (Fig. 3). The Buck Mountain vein forms the base of the Llewellyn Formation, where it overlies the Pottsville Formation. The Llewellyn Formation was deposited in the Middle and Late Pennsylvanian, during a more tectonically quiescent time than the preceding Pottsville Formation (Eggleston, 1992). The Llewellyn Formation is non-marine and consists of alluvial plain sediments of interbedded dark grey carbonaceous sandstones, conglomerates, siltstones, claystones, and shales in fining upward cycles (Inners, 1988). There is

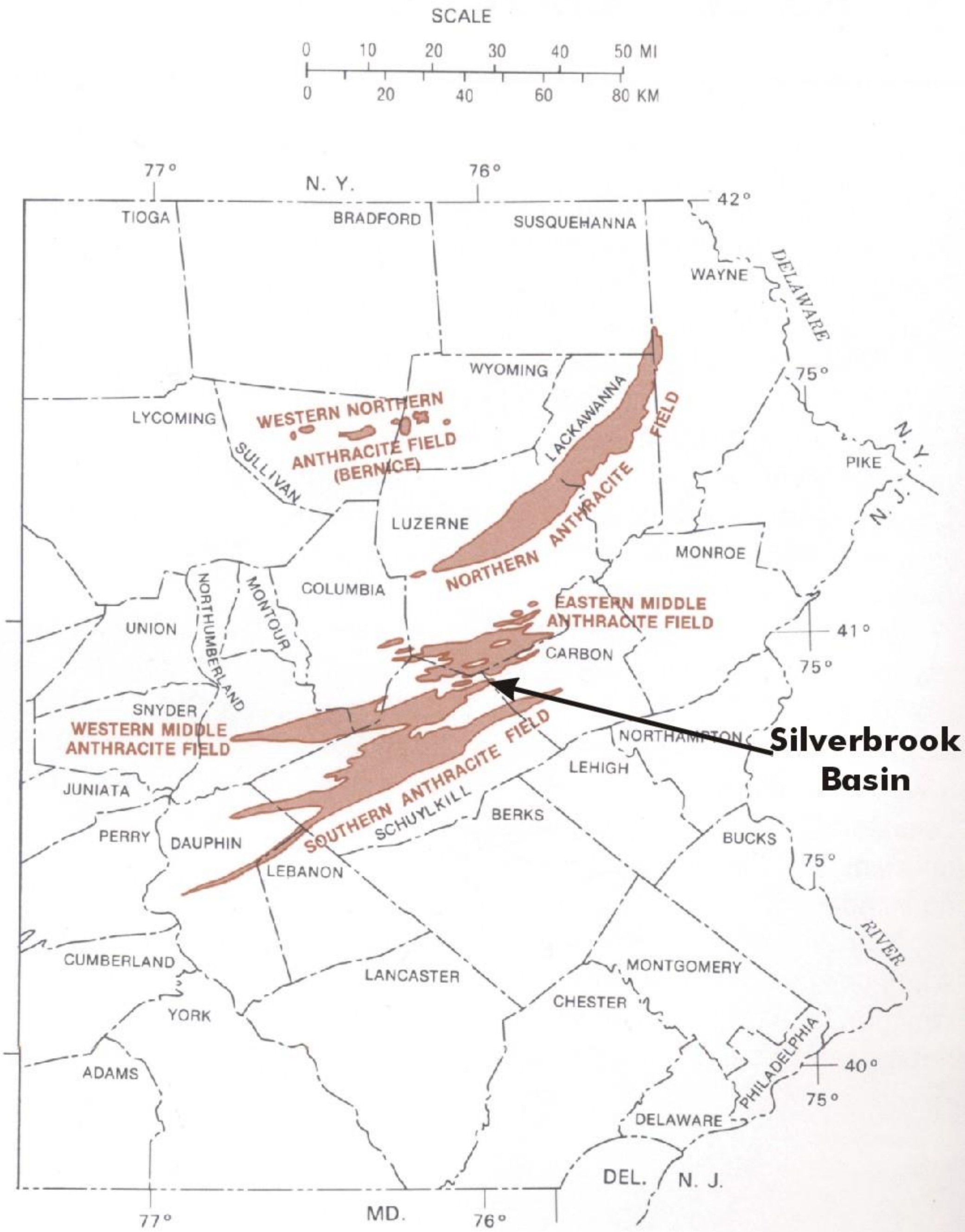


Figure 2. Anthracite region of Pennsylvania (Eggleston et al., 1999, modified from Pennsylvania Geological Survey, 1992).

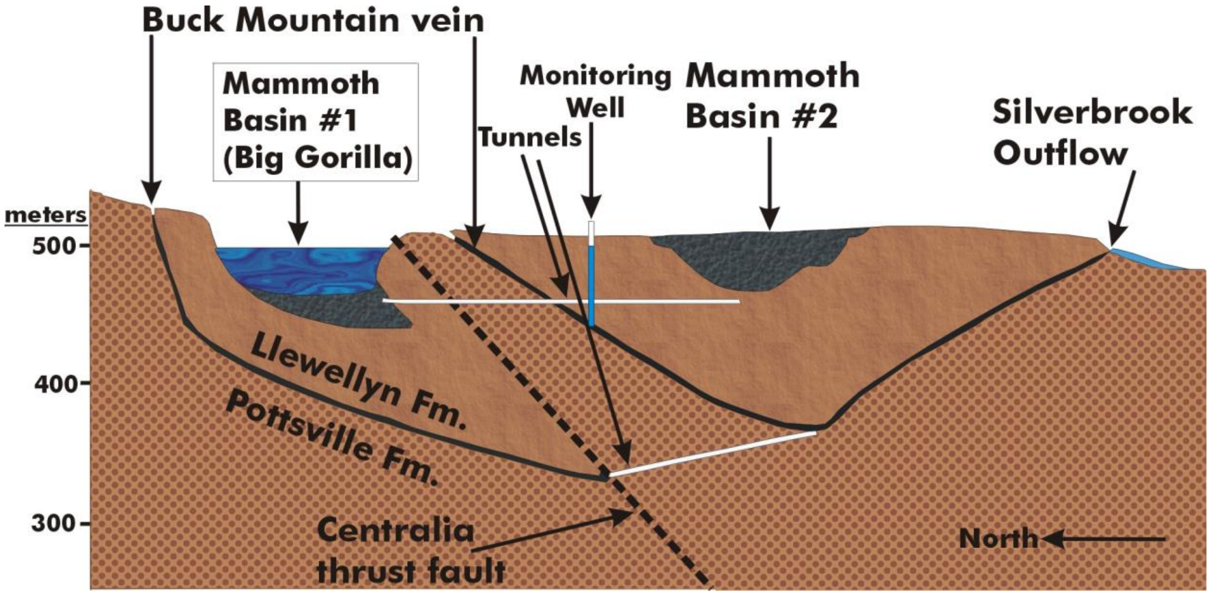


Figure 3. Cross-section of the Silverbrook Basin, constructed from a mine map by J.H. Winters, date unknown. The two Mammoth basins show the former location of the removed Mammoth seam.

little to no alkaline drainage in the Eastern Middle field; thus, it is likely that there are no calcareous strata nearby (Brady et al., 1998).

In the Silverbrook Basin, the Centralia thrust fault has divided both the Buck Mountain and the Mammoth veins, which show approximately 240 m (800 ft) of displacement (Fig. 3). The Buck Mountain vein was deep mined to a depth of approximately 160 m (540 ft) below the surface. A drainage tunnel was constructed between the two lowermost positions of the Buck Mountain vein, crossing the Centralia fault. The Mammoth vein is also present at two locations in the Silverbrook Basin. Once surface mined, the two Mammoth pits were filled with coal washing (reject material) from an adjacent breaker. The Big Gorilla is a water-filled pit that was mined once for anthracite from the Mammoth vein, and a second time for coal silt. The second Mammoth pit still contains coal silt. A horizontal tunnel crosses the Centralia fault to connect the Big Gorilla to the Buck Mountain vein at a depth of 46 m (150 ft) below the surface.

The Big Gorilla mine pool was approximately 510 million liters (135 million gallons) in late 1997. It was 430 m (1400 ft) long, 120 m (400 ft) wide, and 27m (90 ft) at its deepest point. After coal silt from the Mammoth Basin #1 had been reclaimed, the pit gradually filled with water, which became acidic due to the remaining coal silt. Efforts have been made to limit the overland flow into the surface mine pool. However, the Big Gorilla still receives direct precipitation. The water level in the Big Gorilla fluctuated seasonally prior to ash placement. At the conclusion of the Big Gorilla project, the surface mine pool will be entirely filled with ash, brought to the pre-mining elevation, topped with 1.2 m (4 ft) of clean fill, and seeded.

Initially, it was thought that water from the Big Gorilla mine pool would travel through the tunnel connecting it to the Buck Mountain vein, then through the old mine workings until it emerged at the Silverbrook outflow. The Silverbrook outflow is the only discharge point for the Silverbrook Basin, and no information on the rate of transport within the basin exists. Under dry conditions, the Silverbrook outfall forms the headwaters of the Little Schuylkill River. Although the tunnel leading from the Mammoth vein may be clogged with silt, the tunnel and mined section of the Buck Mountain vein are thought to have a higher hydraulic conductivity than the surrounding sandstone. Groundwater flow in a karst system where limestone has dissolved to form conduits and solutionally widened fractures is an analog to the flow in the tunnels and veins within the Silverbrook Basin.

Ash Characterization

The ash at NEPCO is the residual material from burning culm and limestone to produce heat and capture unwanted emissions, respectively. Approximately 1500 Mg (1700 tons) of culm and 54 Mg (60 tons) of limestone are burned daily in a fluidized bed combustor. The limestone contributes both CaO and $CaSO_4$ to the ash.

The fly ash from NEPCO is reddish brown, while the bottom ash particles range from grey to red. Fly ash particles are very fine (4.0 to 3.5ϕ), with an average diameter usually between 62 and 88um. Bottom ash particles range from 100um to 1cm in diameter and are angular.

The mineralogy of NEPCO's fly ash has been determined by a combination of methods including quantitative x-ray diffraction (QXRD), differential thermal analysis (DTA), and wet chemical analysis (Table 1). The meta-clay fraction is the residual clay component from the culm that when heated to 800^{o}C in the burning process, is dehydroxylated. The water molecules between the initial layers are gone, and the clay still retains a platy structure. The meta-clays may act to sorb or desorb ions as well as dissolve. Both portlandite and calcite can dissolve to add alkalinity to pore waters. The quartz is present in the ash unaltered from its state in the culm.

Table 1. Mineralogical analysis of culm-derived fly ash used in the Big Gorilla project.

Mineral	***Formula***	***Analytical method***	***Wt. %***
Quartz	SiO_2	QXRD, wet chem	20.0
Mullite	$Al_6Si_2O_{13}$	QXRD	7.0
Hematite	Fe_2O_3	QXRD	2.0
Portlandite	$Ca(OH)_2$	DTA, QXRD, wet chem	6.5
Calcite	$CaCO_3$	QXRD, wet chem	0.4
Gypsum	$CaSO_4 \cdot 2H_2O$	QXRD	0.5
Meta-clays		QXRD	63.6
Total			100

As dictated by PA DEP's Module 25, NEPCO's fly and bottom ashes must undergo bulk and leaching analysis on a regular basis. Prior to 1995, leachate analyses were conducted using the toxicity characteristic leaching procedure (TCLP), and later the synthetic precipitation leaching procedure (SPLP) was employed. The TCLP and SPLP are also referred to as the U.S. Environmental Protection Agency Methods, 1311 and 1312, respectively. It is common for trace elements to be released upon burning and redistributed into bottom ash, fly ash, fine fly ash, and the gaseous phase (Swaine, 2000). A high proportion of the trace elements As, Cd, Cr, Hg, Pb, Ni, and Se react in a circulating FBC furnace and are captured in ash or CaO particles (Rose and Noll, 2000). Trace elements are often found in higher concentrations in fine particles due to their higher surface area (Helbe, 2000; Rose and Noll, 2000). The bulk chemical analysis of the fly ash shows higher concentrations of toxic metals such as As, Cd, Cr, Co, Hg, and Mo than does the bottom ash. The leachate concentrations for bottom and fly ash are more similar. The average concentrations from samples of both bottom and fly ash from the 1992-1999 period are well below the maximum permitted leachate concentration as dictated by the PA DEP Module 25 (Loop, 2000).

Table 2. Average of values above detection from analyses performed on NEPCO fly and bottom ash in accordance with PA Module 25 regulations from 1992-1999. Maximum allowable leachate concentration values provided for comparison (PA Mod. 25).

	Bulk Analysis	**(mg/kg)**	**Leachate Analysis**	**(mg/L)***	**Max. Leachate**
	Fly Ash	Bottom Ash	Fly Ash	Bottom Ash	**Conc. (mg/L)**
pH	10.67	11.52	9.05	9.06	
sulfate	4901.17	3072.83	488.73	192.88	2500
aluminum	23723.75	12987.50	2.69	2.56	5
antimony	2.47	LF	0.05	0.01	0.15
arsenic	12.86	3.43	0.04	LF	1.25
barium	184.76	105.17	0.15	0.21	50
boron	59.62	10.82	0.31	0.43	31.5
cadmium	1.22	0.68	LD	LD	0.13
chromium	25.15	11.02	0.09	LF	2.5
cobalt	3.62	1.11	LF	LF	
copper	23.24	7.74	0.09	0.07	32.5
iron	6986.38	3767.38	0.14	0.24	7.5
lead	27.47	13.08	0.21	0.13	1.25
manganese	177.39	358.54	0.20	0.21	1.25
mercury	0.6122	0.0395	LF	LF	0.05
molybdenum	10.89	4.18	0.13	0.02	4.38
nickel	10.33	4.83	LF	LF	2.5
potassium	6737.14	4400.00	9.88	7.75	
selenium	15.18	5.47	0.17	0.03	1
silver	3.56	LF	LF	LF	
zinc	15.86	9.50	0.10	0.30	125
nitrate-N			1.27	2.92	
chloride			23.80	54.67	2500
sodium			10.77	5.39	
Total organic carbon			3.01	2.11	
Acid neutralizing potential	665667	1011800			

LD = always less than detection
LF = less than 5 measurements above detection (of 17)
* Leachate analyses were performed by TCLP before January 1995, and SPLP after.

Ash Placement

Land reclamation using fly and bottom ash has taken place in the Silverbrook Basin since 1989; however, the beginning of subaqueous deposition of fly and bottom ash marked a new stage in reclamation, and warranted new methods of placement. The Ellen Gowan project was a small-scale demonstration to evaluate the tendency of ash to flow upon placement in water. It was found that with slow input of ash to the water, platform stability could be maintained without contributing turbidity to the receiving water-filled pit.

At NEPCO, the preliminary platform was constructed from clean fill at the east end of the Big Gorilla mine pool. With increased ash placement, NEPCO constructed an upper and lower platform. The lower platform was employed during warmer months, while the upper platform was used during the winter months to avoid slippery conditions. The lower platform is approximately 9 m (30 ft) from the water surface, and the upper platform is approximately 17 m (55 ft) above the lower platform. Currently, no distinction is made for the location of ash placement, because conditions were not found to be as hazardous as previously thought. Trucks carrying 32 Mg (35 ton) loads place either fly or bottom ash near the ash face (Fig. 4). Bulldozers then push the ash into the mine pool. At the end of 2001, over 1.1 million Mg (1.2 million tons) of ash have been placed in the Big Gorilla. The lower ash platform has advanced over 340 m (1100 ft) from the original point of placement. It is expected that the surface mine pool will no longer exist by 2003.

Figure 4. Truck and bulldozer placing ash from the lower platform into the Big Gorilla surface mine pool.

Ash Stability

The use of trucks and bulldozers in regular placement activities provided the only mechanical compaction of the ash platforms. When driving or walking on the ash, there is no indication of soft areas or water accumulation. NEPCO is required to submit ash samples to undergo a Proctor test (ASTM, 2001) every six months. The results from the Proctor test provide a theoretical maximum density, as well as an optimum moisture content. Also, the PA DEP's Pottsville office regularly monitors the density and moisture content of the ash platform using a ^{137}Cs densitometer, following the guidelines outlined in the Troxler product manual. Based on both procedures, within three months, the density of the ash placed on the platform is consistently 90-100% of the theoretical maximum. The weight bearing capacity is measured in the field with a penetrometer by PA DEP, and is routinely over 69 MPa (5 tons per square ft). The bearing capacity was also measured by the S&F Drilling Company, who measured a bearing capacity of greater than 27 MPa (2 tons per square foot).

Two test borings were drilled into the lower ash platform on July 16-18, 2001, almost four years after ash placement began. Test boring 2 was drilled in ash less than six months old, while test boring 1 was drilled in ash approximately three years old. Split spoon testing was conducted to determine density (U.S. Department of the Interior, 1974). Both borings showed increased blow counts in the first 1.5 m (5 ft) of ash, approaching rejection. Test boring 1 showed a much greater hardness between the 15 and 23 m (50 - 75 ft) depth, with an average of 25 blow counts per foot. Test boring 2 had less than 5 blow counts per foot in the 15-23 m (50-75 ft) interval. Increased blow counts per foot reflects greater chemical reaction in a stronger sediment pile.

Samples from the test borings underwent x-ray diffraction analysis using a Scintag Pad V diffractometer, and were mounted with vaseline on a silicon metal zero background slide. The samples showed no marked mineralogical difference from the pre-placement fly ash. Both contain quartz and a clay phase, which most nearly matches muscovite. Scanning electron microscopy (SEM) was used to determine visually whether new, possibly cementitious, minerals were forming in the ash. Indeed, cementitious phases were observed with the SEM in test boring 1, at the 15-16 m (50-52 ft) interval.

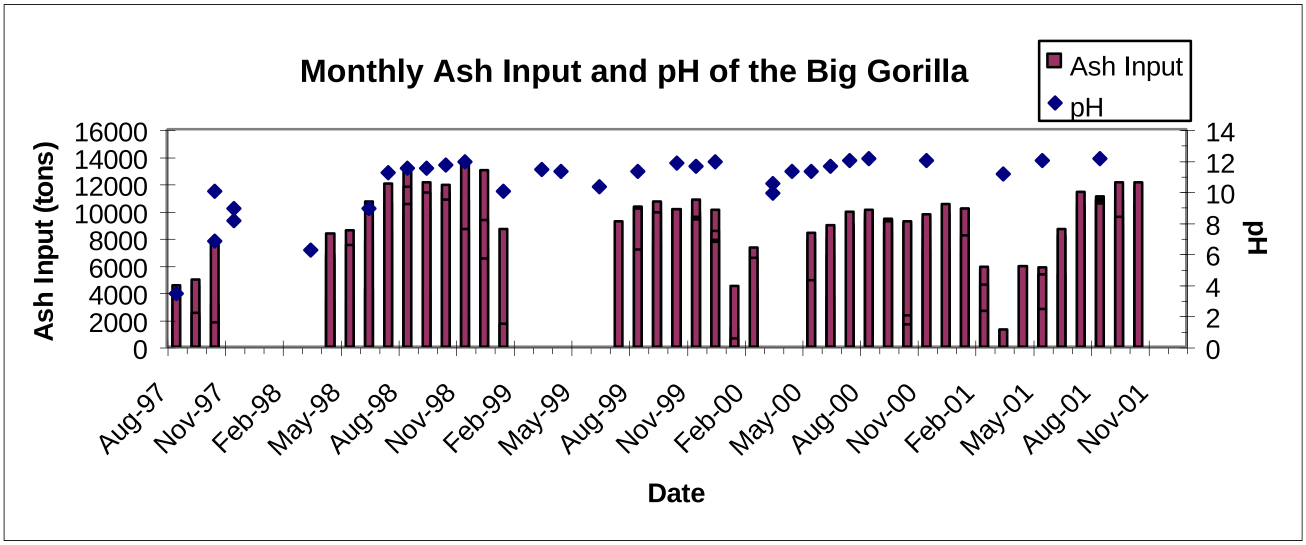
Before drilling the two test borings discussed above, a boring was drilled to 5 m (17 ft), cased and abandoned. The abandoned boring was used to conduct a falling head test by filling the pipe with water and recording the water level with time. Data were analyzed using the Cooper, Bredehoeft, and Papadopolous curve matching method to obtain estimates of transmissivity and storativity. The transmissivity was approximately 0.3 m^2/day, which is similar to that measured for ashes in the laboratory. The storativity was estimated as 10^{-3}, which is very low for an unconfined aquifer.

Surface Mine Pool Chemistry

Ash placement from the 9 m (30 ft) high platform into the deepest segment of the mine pool immediately caused turbidity boils to form approximately 90 m (300 ft) from the ash face. This movement in the water was caused by the transport of fine fly ash particles throughout the water column to the bottom of the pit, where it was redirected to the surface. As the project continued, and the filling moved beyond the deepest portion of the pit, the boils diminished. The fine-grained portion of the ash travels to the far end of the mine pool, and can be seen on wallrock and in sonar images of the bottom of the mine pool. The churning of the mine pool water by fine grained particles causes the water to be chemically homogeneous, with the exception of atmospheric equilibration in the top few feet of the water column. Prior to ash placement, there was a distinct stratification in the water column. The initiation of ash input to the mine pool also caused a dramatic change in the pH value and metal concentrations of the water.

Before August 1997, the mine pool water had a pH value of 3.6. In the first two months of ash placement, the pH had reached 10.0 (Fig. 5a). During the first winter, when ash input from the lower platform had been suspended, the pH value dropped to 6.2. When ash input to the mine pool resumed in the spring, pH values again rose to 11.4 in July 1998, and since then have rarely dropped below 11. The alkalinity produced by the ash has buffered the pH between 11.0 and 12.2. CaO can raise the pH in the Big Gorilla water to a theoretical limit of 12.45, due to thermodynamic equilibrium with $Ca(OH)_2$. The alkalinity in 2001 was close to 600 mg/L $CaCO_3$, but dropped to 90 mg/L $CaCO_3$ when quantities of ash placed decreased in March (Fig. 5b). Alkalinity in the Big Gorilla mine pool has varied between 34 and 626 mg/L $CaCO_3$ since August 1998.

a)



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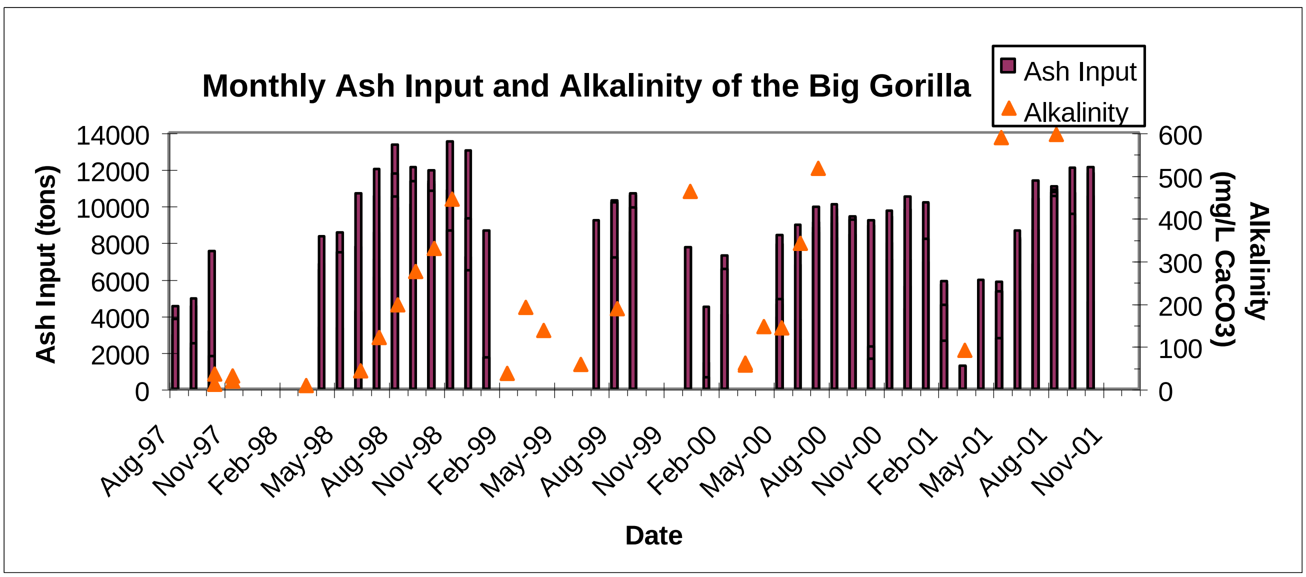

Figure 5. The response of pH (a), and alkalinity (b) to ash input to the Big Gorilla.

The major metals associated with acid mine drainage all decreased in concentration with ash input. Aqueous concentrations of Fe, Al, Mn, and Zn in the Big Gorilla decreased dramatically in the first three months following ash input (Table 3). Mg concentrations were lowered from above 4 mg/L to below 1 mg/L within a year of ash input. With increasing pH and alkalinity, it is likely that the dissolved concentrations of Al, Fe, Mn, Zn, and Mg formed hydroxides and precipitated to the bottom of the mine pool. Such precipitation was predicted by PHREEQC, a

U.S. Geological Survey geochemical model that calculates conditions at thermodynamic equilibrium (Parkhurst, 1995). Traces of the oxide phases were not detectable in the test borings drilled in 2001.

Table 3. Selected chemical analyses from the Big Gorilla mine pool, analyzed by PA DEP. All concentrations are total and for a surface sample, except for 10/27/99, which was taken at a depth of 6m (20 ft).

Concentration (mg/L)	6/7/93	7/2/93	10/28/97	10/27/99	8/28/01
Al	3.5	4.2	0.57	0.38	0.41
Fe	0.52	0.40	0.11	<0.020	0.15
Mn	0.71	0.72	0.011	0.010	0.014
Zn	0.22	0.20	0.008	0.052	<0.010

Mine impacted waters are regulated at a level of 25 times the established drinking water limit, as required by the Pennsylvania Module 25. Trace metal concentrations in the Big Gorilla mine pool are all below those levels (Loop, 2000). Ni has no EPA regulated limit, and the average concentration for those samples that were above the detection limit was 0.093 mg/L. Ba concentrations were all an order of magnitude below the drinking water limit of 2.0 mg/L. Cu concentrations are consistently below the secondary drinking water limit of 1.0 mg/L. Aqueous concentrations of Cd, Hg, and As have been less than the analytical detection limit for a majority of the samples taken from the Big Gorilla surface mine pool, and like Cr, Pb, and Se, always fall below the limit of 25 times the drinking water limit.

While some elemental concentrations decrease with ash input (Fe, Al, Mn, Zn, and Mg), for others it is difficult to distinguish trends due to the low concentrations present in the mine pool. Cr, F, Cl, Na, Si, K, and possibly Ba aqueous concentrations fluctuate in response to ash input, decreasing when ash placement is suspended.

In July 1998, a faint trace of white precipitate was observed around the rim of the Big Gorilla mine pool, and by October 1999, this became a distinct continuous rim (Fig. 6). Both the variation in water level and the uptake of CO_2 in the first few feet of the mine pool produced a 1.2 m (4 ft) high white rim. The white material was scraped from the wall, underwent XRD, SEM/EDS, and wet chemical analysis, and was determined to be calcite, $CaCO_3$, as predicted by PHREEQC. SEM images show plates of material that are flat on one side with spherical shapes on the other. Upon closer inspection, the spheres displayed a pinecone texture, with rectangularended wedges (Fig. 7). Small amounts of gypsum were also seen with SEM analysis and indicated by wet chemical analysis.

Figure 6. White rim present in Big Gorilla mine pool, October 1999.

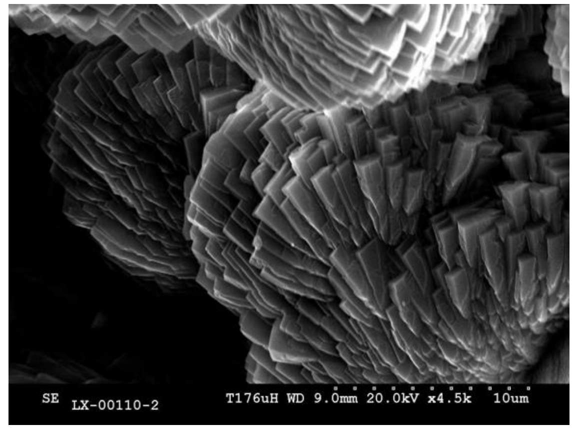

Figure 7. SEM image of calcite formed on the edge of the Big Gorilla mine pool (4500X).

Basin Chemistry

The Silverbrook Basin is approximately 1.6 km (1 mi) wide and 8 km (5 mi) long, with one discharge point at the Silverbrook outfall. The Silverbrook outfall forms the headwaters of the Little Schuylkill River under low flow conditions. With higher flow, the Little Schuylkill River is heavily impacted by acid mine drainage from other sources prior to intersecting the Silverbrook outfall.

Other monitoring points in the basin include four wells that had been drilled prior to ash placement in the Big Gorilla (1, 2, 3, and 9). A fifth permanent well was constructed in August 2001. Three test borings were drilled at approximately the same time. Two of the borings are located in the lower ash platform, and a third is in the culm area at the west end of the Mammoth Basin #1.

Well #1 was used to monitor prior land reclamation, and is no longer sampled. Wells 2, 3, and 9 all have unique chemical signatures that show no change with ash input to the Big Gorilla. That well #3 shows no effect of the chemical change is particularly striking, since it is located less than 20 m from the mine pool, and was drilled to intersect the horizontal tunnel that connects the Big Gorilla to the Buck Mountain vein.

Because the water level does not increase in proportion to ash input, and seasonal water level fluctuations occur in the Big Gorilla, it was thought that water was leaving the system. Another permanent well was drilled into the Buck Mountain vein on the southern side of the Centralia fault (Fig. 3) in an attempt to intersect water traveling from the Big Gorilla to the Silverbrook outflow. The Buck Mountain well was pumped at a rate of 57 liters per minute (15 gpm) for one hour with a head change of less than 0.1 m. Water from the well alternated between clear and black, but consistently had a pH of 4.1. Thus, none of the permanent wells sampled have shown any indication of a response to ash input in the Big Gorilla surface mine pool.

Aqueous chemical data have been gathered at the Silverbrook outflow since 1989. Elemental concentrations at this outflow point may reflect a number of factors including: seasonal climate and flow variation, reclamation activities (land and subaqueous), and colloidal transport. At times these factors are interrelated to the extent that they obscure the direct cause of chemical variation. A most obvious response to ash input from the Big Gorilla surface mine pool would be an increase in the pH value or the alkalinity, yet no discernable change has occurred in either parameter.

In looking at the Silverbrook outflow data from August 1989 to January 1997, one can see a distinct change in the slope of calcium concentration with time. This occurs in early 1992 (Fig. 8). There is a similar change in the calcium concentration at the beginning of 1997, prior to ash placement in the Big Gorilla. Because the ash used for land reclamation is the same as that for placement in the Big Gorilla, it also contains a chemically active fraction of calcium in the form of CaO. Old fractures or tunnels could convey calcium-rich water that had been in contact with the ash into the subsurface pool, which would be drained by the Silverbrook outflow. The timing of this transmission is uncertain. However, in 1992, the area to the east of the ash silos was being reclaimed, and in 1997, the area to the east of the Big Gorilla was being reclaimed.

In early 1997, the greater increase in calcium concentration was accompanied by an increase in seasonal variation of Fe, Al, Mn, SO_4, Cl, and Na, as well as total dissolved solids (TDS) in the Silverbrook (Fig. 9). Chloride and sodium were at their lowest concentrations in October and highest in April, while the reverse was true for the other parameters. October has typically been a peak month for ash deposition into the Big Gorilla mine pool, but it is also characterized as a month of low precipitation and flow. It is possible that the rains in April dilute most of the chemical constituents, but carry with them dissolved sodium and chloride from the salting of roads as the rainwater percolates through the land surface. In October, any mineral salts that may have formed from the oxidation of minerals will be washed from the system with only small amounts of water, therefore appearing concentrated.

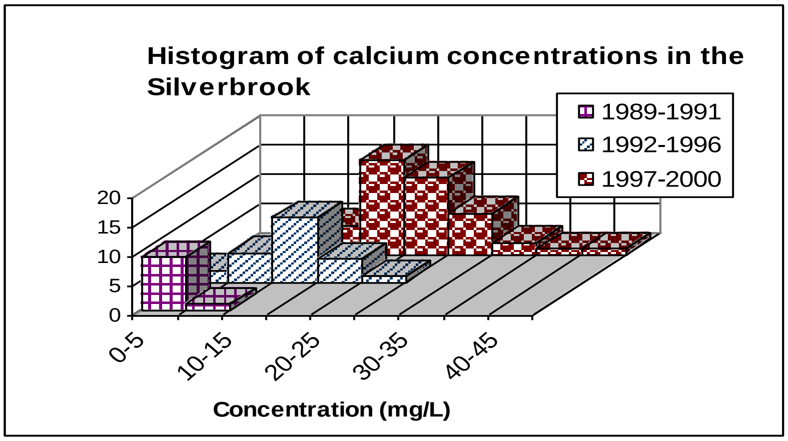

Figure 8. Histogram of calcium concentration in the Silverbrook outfall.

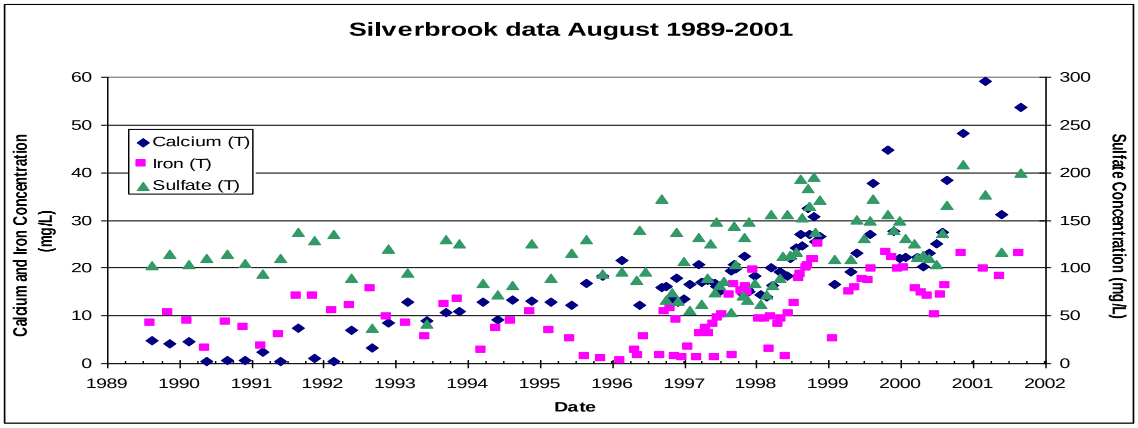

Figure 9. Iron, sulfate, and calcium in the Silverbrook outflow, 1989-2001.

Conclusions

The Big Gorilla demonstration project, designed to study the effects of placing dry ash in standing mine water, has been considered a success for a number of reasons. The ash platforms have been structurally stable, acquiring a density of 90-100% of the theoretical maximum in less than three months. The high pH and alkalinity of the Big Gorilla mine pool has caused a decrease in the concentrations of Fe, Al, Mn, Zn, and Mg. All other metals remain within acceptable limits for mine drainage water. Although the pH and alkalinity have not changed in the Silverbrook, and there is no evidence of chemical influence from the Big Gorilla, in this study we have discovered that land reclamation within the basin leads to a change in the form and variation of chemical constituents in the Silverbrook outfall. The filling of the Big Gorilla surface mine pool will in time remove a conduit for the continued production of acidic mine water as well as a physical surface hazard.

Important factors in the success of this project include the preliminary studies of placement for structural stability (Ellen Gowan project) and the well-defined basin geology and hydrogeology. Because the Silverbrook Basin has only one discharge point, it provided an effective way to monitor basin-wide changes. Chemical data for the Silverbrook outfall had been collected since 1989, so a baseline was clearly established prior to ash placement in the Big Gorilla. The chemistry of the ash at NEPCO has been key to the stability of the ash platform and the chemistry of the mine pool water. The fluidized bed combustor has contributed CaO, $CaSO_4$ and $CaCO_3$ to the ash, which in turn produced alkalinity upon contact with the mine pool water. The ash is not high in sulfur or highly enriched with toxic metals.

Future work on the chemical influences within the Silverbrook Basin include column experiments using ash and culm, in an effort to predict chemical interaction within an area such as the Silverbrook Basin. This study should elucidate the possible extent of mixing between the surface and subsurface mine pool. Long-term monitoring by NEPCO and PA DEP will occur until after the mine pool area is reclaimed.

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