ALKALINE OVERBURDEN ADDITION TO ACID-PRODUCING MATERIALS TO PREVENT ACID MINE DRAINAGE[1]

Jeff Skousen and Glenn Larew[2]

Abstract: Alkaline addition to acid-producing overburdens during surface mining and reclamation has shown variable results in improving postmining water quality. This paper describes a mining operation where acid mine drainage from an abandoned deep mine was eliminated by surface remining the deep mine workings and adding alkaline material during reclamation. About 15,000 mt/ha (6,600 st/ac) of alkaline shale were hauled to the remined site and placed on the pit floor and also on top of toxic material placed "high and dry" in the backfill. No acid mine drainage has come from the site during the past 2 yrs since reclamation. The cost of hauling the alkaline material to the site was about \$9,880/ha (\$4,000/ac). Chemical treatment costs of acid mine drainage previously coming from the site before remining were projected to be \$8,000 to \$15,000/yr depending on the chemical reagent.

Additional Key Words: acid-base account, coal spoil, overburden analysis, remining, special handling.

Introduction

Accurate prediction of acid mine drainage (AMD) before surface mining requires a complete understanding of many components at a mine site. Three of the most important factors are 1) overburden geochemistry, 2) the postmining hydrology of the site, and 3) method and precision of overburden handling and placement in the backfill during reclamation.

Overburden Geochemistry

Premining analyses of soils, overburden, and the coal pavement are required by law to ascertain the physical and chemical characteristics of the strata above and immediately below the coal bed. Overburden analysis and characterization provides important information about overburden layers that are acid toxic, potentially acid-producing, neutral, potentially alkaline-producing, or alkaline. Overburden analysis for surface mining begins with acid-base accounting. This analytical technique provides a simple, relatively inexpensive, and consistent procedure to evaluate overburdens. It balances potential acidity (based on sulfur content) against total neutralizers (mostly carbonates, measured by reaction with hydrochloric acid) in an overburden sample. Samples containing more acid potential than alkaline material for neutralization result in values in the "max needed" column, while the reverse causes "excess" values (Skousen et al. 1990). On rock layers where low values in max needed or excess columns give little information relative to the chemical production potential of the rock, it may be helpful to subject the overburden sample to leaching/weathering analyses. These additional analyses provide more information than that given by the acid-base account and often help designate how that particular rock may react in a backfill. Identification of the chemical production potential of overburden layers aids in developing overburden handling and placement plans. It is then critical for each operator to carefully follow the overburden handling and placement prescription based on overburden characterization for the particular site.

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[2] Jeff Skousen, Associate Professor and Extension Reclamation Specialist, West Virginia University, Morgantown, WV, USA; Glenn Larew, President, Coaltrain Corporation, Reedsville, WV, USA.

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Spoil Hydrology

The hydrology of a backfill and its effect on AMD are very complex, and research on the movement of water into and through a mine backfill has provided little information on how to control AMD. The movement of water over the surface and into and through the backfill is not well understood, but it is a significant factor in preventing and controlling AMD. Generally, the porosity and hydraulic conductivity of the materials in a backfill are greater than those of the consolidated rock overburden that existed before mining, and changes in flow patterns and rates should be expected after mining (Caruccio and Geidel 1989). Often, the fine-grained topsoil placed over the backfill conducts water more slowly than the underlying coarser material, and thus the topsoil may determine the amount and rate of water movement into the backfill (Guebert and Gardner 1992). As water moves into the coarse material in the backfill, it follows the path of least resistance, flowing through the more permeable acid sandstones and around the calcareous shales, and continues downward until it encounters a barrier, the pavement, or other compacted or slowly permeable layer. Water does not move uniformly through the backfill by a consistent wetting front. The chemistry of the water emanating from the backfill will reflect only the rock types encountered in the water flow path and will not be related to the geochemistry of the total overburden (Ziemkiewicz and Skousen 1992).

Overburden Handling and Placement

The prevailing approach to control AMD in the Appalachian Coal Region of the U.S. is to keep water away from pyritic material. Recommendations have focused on segregating and placing acid-producing materials on top of a 1- to 2-m (4- to 6-ft) layer of nontoxic material on the pavement, placing the toxic material above the water table, and then treating, compacting, and covering it with a clay cap or other type of sealant material to reduce surface water infiltration into this material (Skousen et al. 1987). Diverting surface water above the site to decrease the amount of water entering the backfill is also recommended.

In areas where limestone or other alkaline layers occur in the overburden, blending of overburden materials may be used where the alkaline materials are capable of neutralizing the acidic materials. The topsoil should be limed to neutralize any residual acidity and to raise the pH for vegetation establishment. Water courses above the mined areas with low mineral acidity can also be limed to improve water quality.

Alkaline Addition

Importing alkaline materials to mine sites to offset the acid-producing potential of overburdens has shown variable success (Brady et al. 1990, Hamric 1993, Ziemkiewicz and Skousen 1993). On some sites where this practice has been implemented, AMD has been reduced (Brady et al. 1990). For example, Meek (1991) documented that selective placement of overburden with alkaline addition reduced AMD production 40 to 50%. However, none of the AMD prevention techniques employed on Meek's sites were completely successful in eliminating the production of AMD. In fact, the greatest reduction of AMD (70%) was achieved on his sites with selective placement of overburden and covering the acid-producing material with a PVC liner.

The objective of this study was to evaluate the effectiveness of importing and adding alkaline shale overburden as an amendment to acid-producing materials to prevent AMD. The costs of treating AMD were compared to the costs of adding alkaline material to assess the economic feasibility of alkaline addition during surface mining and reclamation.

Site Descriptions and Methods

Coaltrain Corp. mines coal from the Upper Freeport, Bakerstown, and Pittsburgh beds (Pennsylvanian System, Allegheny and Conemaugh Groups) in northern West Virginia. The company is a small, family-run operation employing 12 to 18 men. Coaltrain operations have worked at two locations concurrently. The first operation has generally mined in the Bakerstown coal bed, while the other was either a Pittsburgh or Upper Freeport coal remining operation. Because of the alkaline nature of Bakerstown coal overburden, the most alkaline portions of this overburden have been used as an alkaline amendment to the potentially acid-producing Pittsburgh and Freeport coal overburdens.

Bakerstown Operation

In 1986, Coaltrain received a permit to mine 28 ha (70 ac) of land underlain by the Bakerstown coal near Masontown, WV. The premining land use was pasture, and the surrounding land use was predominately pasture and hayland for cattle. The overburden was characterized by 9 m (30 ft) of gray shale, 7.6 m (25 ft) of alkaline red shale and limestone, and 4.5 m (15 ft) of fractured sandstone (table 1). The alkaline red shale on the site correlates to the Pittsburgh Red Shale described by Hennen and Reger (1913), and contains nuggets of impure limestone and is generally red or purple in color. Due to this red shale in the overburden, no AMD has been documented with surface mining of the Bakerstown coal in this area. In fact, disturbance of this overburden material has often improved the water quality of surrounding streams to pH values greater than 7.5.

Contour haulback mining methods were used on the site. The overburden was blasted by the use of an emulsion explosive because of the high water content of the overburden. A Clark 475C loader (12-cu-yd bucket) was employed for overburden removal into two International 350 Pay Haulers, each carrying approximately 50 st of rock. A Fiat Allis HD 31 bulldozer was used for regrading and backfilling the site. The Bakerstown coal was extracted using a 7-cu-yd front end loader and hauled by truck to a nearby coal stockpile facility where it was mixed with other coals. Annual coal production at the site between 1988 and 1991 averaged 55,000 mt/yr (60,000 st/yr). No water quality problems were experienced during surface mining. Approximately one-fourth of the alkaline red shale in the overburden was separately loaded and hauled to the nearby Upper Freeport operation.

Upper Freeport Operation

The Upper Freeport job was located about 1.6 km (1 mile) northwest of the Bakerstown site. The site was a surface remining operation which daylighted abandoned deep mines. Little topsoil was available on the site; however, the small amount found on the site was saved and stockpiled. The overburden was characteristic of the Upper Freeport coal with respect to rock type. Approximately 18 m (60 ft) of massive and fractured sandstones along with 3 m (10 ft) of gray shale were present. According to data from the acid-base account, the overburden on this site had more neutralization potential (NP) than many other Upper Freeport overburdens in this area (table 2). However, AMD from an old deep mine on this site and other surrounding abandoned deep mines had contaminated the receiving stream, Mountain Run, for decades and verified the acid-producing potential of the coal and overburden in this area (table 3). Knowing of the extreme alkaline material nearby on the Bakerstown job, Coaltrain decided to remove the old stumps of Upper Freeport coal by remining and eliminate acid mine drainage by importing alkaline material from the Bakerstown job to this Freeport site.

Selective handling and placement of acid-producing materials along with importation and placement of alkaline material on the pavement was deemed an essential element of the mining and reclamation plan. Compaction of the acid-producing material would reduce water infiltration and oxygen diffusion into the material, and covering the acid material with alkaline material should reduce the potential of AMD production. With proper identification, handling, and placement of the acid-producing materials, Coaltrain expected that AMD would not be a problem and the old deep mine discharges would be eliminated.

The permit was received in March 1990. One overburden cut averaging 46 m (150 ft) back into the deep mine was taken. Slope at the site was steep; therefore, only one cut was taken before the overburden became more than 21 m (70 ft) thick. The overburden was blasted on 4- to 5-m (16- to 18-ft) centers with ANFO. Blasting was conducted to fracture the rock and shale to facilitate removal with dozers and loaders. However, blasting was controlled so that the acid-producing material was not pulverized. This process was important because large chunks of acid material expose less surface area for weathering and acid generation. The large chunks of acid material also

Table 1. Partial acid-base account of the Bakerstown overburden showing the alkaline nature of the red shale separately loaded and hauled to the Upper Freeport site for alkaline addition.

Sample	Depth m	Strata Thick m	Rock Type	Fizz	S %	Max %S g/kg	NP g/kg	Max Needed g/kg	Excess g/kg	Paste pH
1	0-1.5	1.5	SH	5	0.001	0.1	150.0	---	149.1	7.9
2	1.5-3	1.5	SH	5	0.002	0.1	213.1	---	213.0	8.1
3	3-4.5	1.5	SH	5	<0.001	0.1	569.2	---	569.1	8.3
4	4.5-6	1.5	SH	5	<0.001	0.1	335.9	---	335.8	8.3
5	6-7.5	1.5	SH	5	0.010	0.3	119.8	---	119.5	8.2

Table 2. Acid-base account of the Upper Freeport overburden.

Sample	Depth m	Strata Thick m	Rock Type	Fizz	S %	Max %S g/kg	NP g/kg	Max Needed g/kg	Excess g/kg	Paste pH
1	0-1.5	1.5	Soil	0	0.007	0.2	1.6	---	1.4	4.4
2	1.5-3	1.5	SS	0	0.013	0.4	1.9	---	1.5	4.9
3	3-4.5	1.5	SS	0	0.008	0.2	2.1	---	1.9	5.7
4	4.5-6	1.5	SS	0	<0.001	0.1	2.6	---	2.5	6.4
5	6-7.5	1.5	SS	2	<0.001	0.1	10.6	---	10.5	8.0
6	7.5-9	1.5	SS	0	<0.001	0.1	3.8	---	3.7	7.2
7	9-10.5	1.5	SS	0	0.042	1.3	3.0	---	1.7	6.8
8	10.5-12	1.5	SS	0	0.280	8.7	2.6	6.1	---	6.6
9	12-13.5	1.5	SH	3	0.001	0.1	63.3	---	63.2	7.7
10	13.5-15	1.5	SS-SH	0	0.393	12.3	21.4	---	9.1	7.3
11	15-16.5	1.5	SH	0	0.277	8.7	9.7	---	1.0	7.7
12	16.5-18	1.5	SS-SH	0	0.103	3.2	27.6	---	24.4	7.7
13	18-19.5	1.5	SH-SS	0	1.050	32.8	30.3	2.5	---	7.2
14	19.5-22	2.5	COAL	0	2.160	67.5	1.6	65.9	---	4.6
15	22-23.5	1.5	SH	0	0.173	5.4	6.3	---	0.9	7.0

required less alkaline material for neutralization. The alkaline material was a friable shale that weathered very rapidly, reacted quickly, thereby releasing nearly all of its neutralizing capability.

The overburden was removed with an International 400 loader and two International 50-st trucks. The acid material was compacted and covered within a day or two of its excavation to prevent oxidation and leaching. Coal was mined by a 7-cu-yd loader in two lifts, loaded into trucks, and taken to the coal stockpile. A black shale binder of 7- to 15-cm (3- to 6-in) thick in the coal was removed and handled separately. Once the bottom coal was loaded from the Upper Freeport bed, about 1 m (3 ft) of alkaline red shale from the Bakerstown job was placed on the Upper Freeport coal pavement and covered with overburden. As trucks hauled coal out, alkaline shale was backhauled in. The pit floor was covered with alkaline shale the same day coal was removed.

The black shale binder between the breast and bottom coal in the Upper Freeport coal bed was placed about 6 m (20 ft) above the pavement and compacted. It was then covered with 0.3 m (1 ft) of alkaline red shale from the Bakerstown job. These layers were then compacted by bulldozers and trucks. Backfilling continued until approximate original contour (AOC) was reached, and topsoil was replaced on the surface. Several inches of alkaline shale were also spread on the surface and mixed with the topsoil.

Results and Discussion

The amount of alkaline material imported to the Upper Freeport site from the Bakerstown job was about 15,000 mt/ha (6,600 st/ac). This amount represented about 1 m (3 ft) of alkaline material if it was spread evenly over 0.4 ha (1 ac) of mined area. Using the data from the acid-base account, the alkaline material from the Bakerstown job had NP values greater than 300 mt $CaCO_3$ equivalent per 1000 mt material (or g/kg). The shale binder in the Upper Freeport coal bed showed a deficiency (or max needed) of about 60 g/kg to neutralize the acid created from pyrite oxidation. Theoretically, 0.3 m (1 ft) of Bakerstown alkaline material (300 g/kg excess) should neutralize the acidity generated from 1.5 m (5 ft) of Upper Freeport toxic material (60 g/kg max needed) if the particle size of the two materials is similar.

In reality, the Upper Freeport overburden contained only 15 cm (6 in) of toxic material (60 g/kg max needed) and 6 m (20 ft) of potentially acid-producing material (ranging from 6 g/kg max needed to 5 g/kg excess). Based on the blasting technique, the particle size of the materials favored the alkaline material. When these items are all considered together, a large safety factor was built in by importing 1 to 1.3 m (3 to 4 ft) of alkaline material from the Bakerstown job when only about 0.3 m (1 ft) was theoretically needed.

The quantity of alkaline material transported to the Upper Freeport job represented a cost of about $0.55/mt ($0.50/st) of coal removed. An average of about 18,000 mt/ha coal (8,000 st/ac) was removed, making the cost of hauling the alkaline material to the site around $10,000/ha ($4,000/ac). This cost only included hauling the material from the Bakerstown job to the Upper Freeport site. Handling and compaction costs were integrated into the method of mining and done in concurrence with normal mining. Therefore with a little advance planning and coordination, these costs were minimal.

Water quality from the deep mine before remining averaged about pH 3.7 and 75 mg/L total acidity (table 3). After the site was remined and reclaimed, water collected in a pond located immediately below the previous old deep mine discharge averaged a pH above 7.0 (table 3). No acidity has been measured in water samples, and iron and manganese in the water have always been within the U.S. Environmental Protection Agency's National Pollutant Discharge Elimination System (U.S. EPA NPDES) effluent limits over a 2-yr period. Chemical treatment of the water is unnessary.

Unfortunately, the flow and low acidity (95 L/min and 75 mg/L) of the AMD from the deep mine was not a significant contributor to the total acidity in Mountain Run (table 4). The quantity of water in the stream was 20 to 50 times greater than the flow from the deep mine and improving the quality of the water coming from the remined

Table 3. Water quality of the deep mine discharge before mining (data before 4/91) and from ponds after mining on the Upper Freeport operation.

Date	pH	Total Acidity mg/L	Iron mg/L	Manganese mg/L	Suspended Solids mg/L
11/89	3.7	73.5	2.65	0.40	<1
12/89	3.8	88.2	3.54	0.60	4
1/90	3.7	68.0	3.00	1.00	14
4/91	6.7	<1	<.05	0.02	7
11/91	7.3	<1	.31	0.40	2
3/92	7.5	<1	<.05	0.24	<1
6/92	7.8	<1	<.05	0.03	<1
9/92	7.4	<1	<.05	0.04	3
12/92	7.5	<1	<.05	0.02	3
3/93	7.7	<1	<.05	<0.01	9
4/93	7.5	<1	.10	0.48	4
6/93	7.4	<1	<.05	0.07	1

Table 4. Water quality of Mountain Run, the stream that receives acid mine drainage from abandoned deep mines before remining (data before Mar 90) and after remining (data after 1/90).

Date	Flow L/m	pH	Total Acidity mg/L	Iron mg/L	Manganese mg/L	Suspended Solids mg/L
11/89	1,064	3.5	92.0	0.36	0.34	<1
12/89	1,216	3.4	78.0	2.67	0.41	<1
1/90	1,349	3.5	48.0	1.26	0.28	<1
9/93	552	3.6	77.0	0.30	0.88	4
12/93	608	3.5	64.0	2.89	0.41	13

Table 5. Annual and 20-yr water treatment costs with various chemicals of a 95-L/m (25-gpm) flow and 75-mg/l acidity.

Chemical	Annual cost	20-yr cost
Caustic Soda	8,489	169,780
Soda Ash Briquettes	15,278	305,560
Ammonia	9,712	194,240
Hydrated Lime	14,545	290,900

site showed no overall improvement in the quality of Mountain Run. In fact between January 1990 and September 1993, the flow in Mountain Run appears to have decreased by half (roughly 500 L/min), and reducing the flow from the remined site (averaging around 25 L/min) would not have decreased the stream flow by that much. No other active mining jobs are operating in the watershed above the Coaltrain Operation, so it is not clear why the flow has decreased. Other remining permits are being sought by Coaltrain to continue to daylight surrounding abandoned deep mines. Only when more of the deep mines with acid discharges are remined and reclaimed will a significant improvement in Mountain Run's water quality be realized.

Based on average premining water flows and analyses of the deep mine discharge on the site, the chemical cost for treating AMD on this site would be expected to range from \$8,000 to \$15,000/yr (table 5). These costs were calculated from interviews with mine operators and costs associated with chemical reagent, electricity, labor, and equipment installation, repair, and salvage costs (Skousen et al. 1993). Without eliminating AMD through alkaline addition (and not accounting for the other attending liabilities associated with water treatment and permitting problems), the cost of treatment would range from \$169,000 to \$300,000 over a 20-yr period.

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CONCENTRATED ALKALINE RECHARGE POOLS FOR ACID SEEP ABATEMENT: PRINCIPLES, DESIGN, CONSTRUCTION AND PERFORMANCE[1]

Jack R. Nawrot[2], Pat S. Conley[2], and James E. Sandusky[3]

Abstract: Concentrated alkaline recharge pools have been constructed above previously soil covered acid gob at the Peabody Will Scarlet Mine to abate acid seeps. Preliminary monitoring results (1989-1994) from a concentrated alkaline recharge pool demonstration project in the Pit 4 area have documented a 45 to 90% reduction in acidity in the principal recharge pool groundwater zone. A 23% reduction in acidity has occurred in the primary seep located downslope from the alkaline recharge pools. The initial improvements in water quality are seen as a positive indication that groundwater acidity will decrease further and amelioration of the acid seep will continue.

Additional Key Words: acid seeps, mine refuse, acid mine drainage, alkaline recharge.

Introduction

Covering acid producing coal refuse with 4-ft of soil cover does not preclude pyrite oxidation under the soil cover. When pyrite oxidation does occur overlying soil covers may become acidified and acid seeps may be generated following several seasons of rainfall infiltration and flushing cycles. Burial of potentially acid producing coal waste in a zone of fluctuating groundwater elevations is conducive to chronic acid seep generation when the upslope groundwater chemistry has insufficient alkalinity to neutralize downslope acid groundwater pools generated by the buried refuse. Soil covering after limestone is applied in sufficient quantities to overcome the potential acidity of refuse, or limestone amendment and direct seeding are effective reclamation techniques that enhance long-term vegetation success and establish a favorable acid-base balance (Warburton et al. 1987, Nawrot et al. 1991). These reclamation techniques can prevent the formation of acid seeps and preclude the need for acid mine drainage treatment.

However, after more than three decades of research, treatment of symptoms rather than elimination of the cause has been the focus of much acid mine drainage research (Nawrot et al 1988, Caruccio 1988). In-situ abatement technology (Caruccio et al. 1984, Snyder and Caruccio 1988) can minimize or eliminate acid seeps through an alkaline-loading process, effectively altering the geochemistry of upslope groundwater recharge zones (Caruccio 1968, Geidel 1979). Alkaline groundwater loading is similar to reclamation practices designed to restore (replace depleted neutralization potential) and enhance (establish excess alkaline surface soil zones) alkalinity in surface zones of coarse refuse (Nawrot et al. 1986, Warburton et al. 1987, Sandusky and Nawrot 1992), slurry (Nawrot and Warburton 1987), and pre-law acid spoils (Nawrot et al. 1988). However, constructing zones of excess alkalinity to recharge groundwater increases the potential effectiveness of the reclamation process by directly addressing key physical (topography), geochemical (recharge zone alkalinity), and hydrologic (groundwater quantity and quality) factors.

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[2] Jack R. Nawrot, Associate Scientist, and Pat S. Conley, Researcher II, Cooperative Wildlife Research Laboratory, Southern Illinois University, Carbondale, IL, USA.

[3] James E. Sandusky, Reclamation Manager, Peabody Coal Company, Stonefort, IL, USA.

When chronic acid seeps occur it is generally too late and too expensive to remove or reposition the acid-producing materials. An acid seep is an "after-the-fact" verification of an imbalance in the acid-base equilibrium of the groundwater and/or overburden (Figure 1). Establishment of net alkalinity must be accomplished below the surface zone (0-23 cm) of mechanical neutralization amendment. When measures to prevent acid seeps are unsuccessful, abatement techniques must be implemented. Acid seep treatment is undesirable due to high costs and the need for a perpetual neutralization facility. Alkaline groundwater recharge may be the only practical reclamation technique for acid seep abatement (Figure 2). Although instant success cannot be expected, alkaline recharge strategies may be the only long-term and cost-effective approach to reverse those geochemical processes (i.e., subsurface acidification) that have taken 20-25 years to generate acid seeps. Abatement techniques using an in-situ neutralization approach can be beneficial if site-specific conditions permit alkaline loading of upslope groundwater recharge zones.

Construction of concentrated alkaline recharge pools is a reclamation approach (previously demonstrated by Caruccio et al. 1984) being implemented and monitored at the Peabody Will Scarlet Mine located in Williamson County, Illinois. The Will Scarlet Mine "Old Works" (pre-law) area encompasses approximately 970 ha of acid gob and slurry. The Pit 4 recharge pool demonstration area includes more than 8 ha of pre-law gob that had been disposed of in a final cut and its associated inclines. Following disposal, groundwater recharge eventually (~25 years) increased water elevations to within 0.5 to 1 m of the surface of the buried refuse. Seasonally fluctuating ground water levels produced ideal conditions for pyrite oxidation and downslope acid seep generation. Without some form of acid seep abatement, the seeps in the Pit 4 area would require perpetual treatment. The primary objective of the Will Scarlet Concentrated Alkaline Recharge Pool (CARP) project was to implement a full-scale field demonstration of the alkaline groundwater recharge approach to ameliorate the effects of a chronic acid seep. CARP is based on the principle of alkaline enhancement of groundwater recharge zones located directly above and upslope of buried refuse (Figures 1 and 2). Maximization of alkaline groundwater recharge zones generates upslope alkaline environments that alter the groundwater chemistry and geochemical acid generating mechanism within the buried refuse zone.

The Will Scarlet CARP project evaluated recharge pool construction techniques and monitored the effects of alkaline surface loading on a shallow groundwater recharge area using seasonally inundated alkaline recharge zones constructed upslope of the subsurface acid generation zone (Figure 2). This field demonstration was supported by the U.S. Bureau of Mines-National Mined Land Reclamation Center, the Illinois Abandoned Mine Lands Reclamation Council, and Peabody Coal Company.

Research Methods

The Pit 4 area of the Peabody Will Scarlet Mine was selected as a reclamation demonstration site due to the presence of chronic acid seeps (Figure 3). Pre-project (January 1989) sampling was conducted to identify acid concentration and flow rates. Aerial photo sequences (i.e., 1958 through 1988), topographic maps, and mine operation maps were used to identify coal waste backfill areas contributing to the acid groundwater seeps.

Construction of the Pit 4 concentrated alkaline recharge pools began July 1989. Berms were constructed to impede surface runoff and promote groundwater infiltration within recharge zones (0.6 to 1.2 ha). Alkaline amendments for neutralization loading consisted of a hydrated lime sludge by-product of acetylene gas production (Table 1). The highly reactive (saturated solution pH of 10.4) hydrated lime sludge contained 30-35% moisture prior to drying. To promote maximum alkaline concentrations within the recharge pools, and enhance infiltration, the hydrated lime sludge (applied @ 618 t/ha in September 1989) was rough-disked in the upper 15-23 cm of the spoil terraces. When lime sludge became limited during late summer 1989, Code H (Mississippi Lime Co., Alton, IL) was used to complete all recharge pools.

Table 1. Neutralization treatment potential of selected alkaline waste materials evaluated[1] for alkaline recharge pool amendment.

Waste Product	AMD Treatment Potential (lbs/100 gal/1000 ppm)	Calcium Carbonate Equivalent (% $CaCO_3$)
Acetylene gas sludge	1.04 lbs/100 gal/1000 ppm	121.0
Cement kiln dust (Joppa)	6.25 lbs/100 gal/1000 ppm	79.3
Code H	2.08 lbs/100 gal/1000 ppm	130.0
Hydrated Lime[2]	1.00 lbs/100 gal/1000 ppm	135.0

[1] Determinations were made by direct addition of pulverized solid (0.05-0.1g increments) to 100 ml of a known-acidity solution. The pH of the solution was monitored to an endpoint of 7.0 and total additions recorded (grams). The total weight of each alkaline material required to neutralize 100 gallons of 1,000 ppm $CaCO_3$ (Acidity) solution was then calculated.

[2] The hydrated lime treatment potential reflects the AMD treatment "standard" and was not determined by above methods.

Recharge pools constructed during 1990 consisted of a series of five checkdams perpendicular to the surface drainage pattern of a soil covered refuse area. Checkdams were constructed of existing soil/spoil cover materials from above the buried refuse as well as adjacent spoil materials. Excavation of soil materials for the checkdam construction decreased cover thickness above the shallow buried refuse, thereby decreasing the distance (5-8 cm) and time required for alkaline recharge pool water to infiltrate and intercept the acid groundwater zone within the buried refuse. Downslope perimeters of recharge pools were purposely excavated to the surface of, or within 8 to 13 cm of the acid groundwater pool to maximize mixing of alkaline and acid groundwater. Three checkdams were constructed to impound a maximum of 1.5 to 1.8 m of water at the toe of the deepest recharge pool checkdam; other recharge pools supported temporary inundation ranging in depth from 15 to 56 cm.

Code H was delivered in pneumatic tank trucks and applied upslope of checkdams within each recharge pool at a rate of 618 t/ha. Two additional recharge pools constructed during 1992 incorporated a design change to increase surface water infiltration and groundwater recharge. Rip-rap filled infiltration "chimneys" (1-m wide x 1.5-m long x 1.8-m deep) that extended into the buried refuse were installed at the inside toe of each embankment. Three to five chimneys were installed within each recharge pool. Maximizing the surface acreage for collection and infiltration of watershed runoff was considered an important design consideration to more effectively stabilize and moderate seasonal extremes (volume and alkaline concentration) of alkaline recharge events and groundwater response.

Groundwater/Seep Monitoring

Groundwater was monitored monthly from a network of 11 piezometers installed in the Pit 4 recharge area (Figure 3). Groundwater wells were constructed of 5.1 cm Brainard-Kilman Triloc® slotted (0.25 cm slot size) PVC threaded wellpipe. Wellpipes were installed in backfilled overburden pits to a depth of 1.8 to 2.4 m below the surface. Wells were bailed prior to monthly monitoring. Laboratory analyses included pH, acidity, alkalinity, total iron, conductivity, and sulfates.

Results and Discussion

Seep and Overburden Characterization

Preconstruction (January 1989) sampling of the primary Pit 4 acid seep (Seep 1) identified low pH (pH $\leq$3.6), high sulfates (5170 mg/L), and total iron (820 mg/L). Flow exceeded 280 L/min. Seasonal increases in excess of 450 L/min. have been recorded following early spring (1990, 1991, 1992, and 1993) rains. Seasonal decreases in groundwater elevation and associated seep flows were recorded during mid- to late-summer throughout the four year monitoring program. Seasonal low flow values of <150 L/min. were recorded for Seep 1 during July 1991. Extremely heterogenous composition of graded and backfilled overburden materials further contributed to the "pseudo-karst" conditions in the Pit 4 seep generating area. Large sandstone boulders, weathered shales, and clay lenses associated with graded and ungraded spoilbanks produced an overburden matrix conducive to fracture flow zones of high groundwater velocities [$2x10^{-2}$ cm/sec (40 ft/day)] and isolated zones of compacted, less permeable strata with significantly lower groundwater velocities [$4x10^{-3}$ cm/sec (2 in/day)]. Extremes of groundwater flow as well as seasonal fluctuations in recharge events and seep flow response were factors that were considered when locating, designing and constructing recharge pools.

The 6 ha coarse refuse area located in the final cut and incline above seep 1 consisted of extremely acid (pH $\leq$3.1) black shales characterized by pyritic sulfur values of 3.2 to 9 percent. Refuse was covered by less than 1m of sparsely vegetated (<60% cover) clay, shale, and sandstone spoil materials. Water table elevations within the buried refuse area fluctuated seasonally and ranged from 50 to 200 cm from the soil cover surface.

Seep Monitoring

Water quality monitoring included pre-construction baseline characterization of acid seeps and groundwater in the Pit 4 alkaline recharge demonstration area. Initial monitoring (January-September 1989) of Seep 1 water quality documented baseline acid conditions prior to neutralization amendment. Seep 1 was characterized by chronically low pH (<4.0) and high acidity (>2,500 mg/L $CaCO_3$). High concentrations of iron and sulfates also typified pre-treatment (before August 1989) acid groundwater and seeps.

Seep 1 water quality reflected groundwater chemistry in the well-established acid generating system of the upslope Pit 4 buried refuse area. Although Seep 1 exhibits seasonal fluctuations in water quality (Figure 4), the consistent trend of decreasing acidity from June 1990 through January 1994 suggests that upslope alkaline amelioration of the Pit 4 recharge area is beginning to be effective. A reduction in total acidity of more than 800 ppm (23% reduction in acid load) was recorded for Seep 1 flow quality between 1989 to January 1994 (Table 2). Although a 800 ppm reduction in total acidity would represent a very significant decrease in acid load for almost any chronic acid seep, this four year reduction represents only a partial, and presumably initial, amelioration of the Pit 4 Seep 1 water quality problem. It is anticipated that decreases in acidity will continue as additional recharge pools have been constructed and the cumulative effects of alkaline loading and seasonal flushing in the Pit 4 area combine to establish a more favorable groundwater acid-base equilibrium. Expectations of continued Seep 1 water quality improvement are based on the dramatic acidity decreases being documented in upslope groundwater wells (No. 3, 4, 5) of the Pit 4 final cut refuse system (Figure 4).

At this point in the monitoring of Seep 1, the 800 ppm (23%) reduction in acidity is encouraging. Recognizing that acid seep amelioration is a long term task requiring reversal of geochemical processes that were initiated 20 years earlier, any initial improvement should be viewed as a positive sign that more improvement can be obtained if patience and perseverance are part of the reclamation plan.

Groundwater Monitoring

Groundwater quality has continually improved in the Pit 4 recharge area (wells 3, 4, and 5) that is directly associated with the buried refuse acid groundwater pool. Two wells (4 and 5) are located in the final cut refuse disposal area approximately 230 m upslope of the main seep (No. 1). These wells are affected by approximately 1.4 to 1.8 ha of alkaline recharge pools, which extend more than 305 m upslope of the sampling wells. Well 3 is approximately 107 m upslope of Seep 1, but is located 4.5 to 7.6 m within the spoil side of the Pit 4 refuse disposal area.

Wells 3, 4, and 5 water quality has consistently improved (Figure 4). Average annual (1989 to 1994) acidity has decreased from 80% to more than 90% for wells 4 and 5, respectively (Table 2). These continued annual decreases in acidity are particularly significant and encouraging as occasional seasonal increases in acidity have consistently been ameliorated by subsequent alkaline recharge pool flushing cycles. More frequent alkaline flushing should lead to greater reductions in acid generation as an alkaline environment temporarily replaces a portion of the acid refuse groundwater pool. Eventual cessation, or at best a significant reduction, of the chronic cycle of ferric iron oxidation of pyrite can be expected when either the frequency or duration of alkaline flushing is capable of sustaining a prolonged alkaline groundwater front within the buried refuse system.

Monitoring data through January 1994 for wells 4 and 5 indicate that the initial stage of acid seep abatement has begun. Reductions in acidity included concomitant reductions in total iron and sulfate, indicating that the by-products of pyrite oxidation are decreasing as the acid generating mechanism is being partially abated by alkaline flushing cycles. Reductions of 70 to 95% in total iron and sulfate values between August 1989 to January 1994 in Wells 4 and 5 correlate well with the 83 and 94% reductions in total acidity that occurred during the same period. Further decreases in acidity in the Pit 4 recharge area wells can be expected as two additional concentrated alkaline recharge pools were recently installed in the Middle Incline of Pit 4.

Summary and Conclusion

This ongoing research demonstration evaluated upslope alkaline recharge pools for the purpose of abating an acid seep. During 1989 to 1994 groundwater and seep quality improved within the Pit 4 buried acid refuse zone. Significant decreases were recorded for sulfates, iron, acidity, and conductivity in recharge basin wells, indicating the ameliorative effect of increased recharge pool alkalinity on the acid generating mechanism in the Pit 4 buried acid refuse zone. Continued improvement in groundwater quality within the alkaline recharge zone is expected.

Improvement in the Pit 4 recharge area water quality suggests that annual cycles of alkaline flushing are responsible for a reversal of the chronic acid generation mechanism that had existed for 20 years in the buried refuse areas. Complete elimination of pyrite oxidation in Pit 4 buried refuse areas may not be feasible, due to such variables as fracture flow patterns and inaccessible alkaline loading areas. However, the extremely encouraging results of this reclamation demonstration prompted the installation of additional recharge pools to accelerate the rate of acid seep amelioration in previously untreated areas above Pit 4 refuse zones. Effectiveness of the recharge pool technique is based on a relatively simple principle: acid seep abatement requires upslope enhancement of groundwater alkalinity. Basic considerations for the alkaline recharge pool approach include:

1. use highly soluble alkaline materials (e.g., calcium oxide, or calcium hydroxide waste products) for recharge pool loading sites.
2. maximize the alkaline groundwater flow volume;
3. decrease surface runoff and maximize alkaline infiltration above buried refuse recharge areas;
4. use multiple upslope alkaline recharge pools to increase probability of intercepting groundwater flow paths entering the refuse zone;
5. construct infiltration drains to reduce time required for alkaline diffusion and flushing; and,
6. allow sufficient time (possibly 3 to 5 annual cycles) for alkaline diffusion and transport to the recharge pool and buried acid refuse site.

Time is an important design factor in acid seep abatement. Several seasons of alkaline flushing will be required to reverse the acidification process that may have originally taken 20 to 25 years to generate an acid seep. Alkaline enhancement of the upslope groundwater recharge zone offers an alternative to perpetual treatment by addressing the geochemical process that controls subsurface acid seep generation. As with any reclamation process that directly affects acid-base equilibrium, reclamation success can only be judged by long-term results. The alkaline recharge pool alternative will require long term monitoring, as has been initiated in this research demonstration.

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Table 2. Peabody Will Scarlet Old Works seep abatement project. Seep 1 and Well 3, 4, and 5 mean annual water quality data. Collected monthly August 1989 through January 1994.

		pH	Conductivity (mmhos/cm)	Acidity (ppmCaCO$_3$)	Total Iron (ppm)	Sulfates (ppm)
Seep 1						
	1989–1990	3.4	4.3	3764	753	5240
	1990–1991	3.5	4.2	3165	672	4605
	1991–1992	3.7	3.9	2940	683	4637
	1992–1993	3.4	3.2	3010	681	4329
	1993–1994	3.2	3.2	2893	640	4295
	Percent Decrease[1]		27	23	12	18
Well 3						
	1989–1990	2.5	5.2	6738	1128	7722
	1990–1991	2.8	4.1	3292	616	4211
	1991–1992	3.0	4.3	4101	707	5185
	1992–1993	2.5	3.5	4007	714	5062
	1993–1994	2.6	3.1	3595	622	5013
	Percent Decrease[1]		42	47	40	34
Well 4						
	1989–1990	2.5	5.4	7725	1476	8684
	1990–1991	2.7	5.2	5359	1452	7610
	1991–1992	2.9	4.4	3990	993	4843
	1992–1993	2.7	3.2	2393	559	3279
	1993–1994	2.7	2.3	1318	269	2385
	Percent Decrease[1]		57	83	81	72
Well 5						
	1989–1990	2.6	13.4	11859	6366	19380
	1990–1991	3.4	4.0	2953	960	4081
	1991–1992	3.6	3.5	2224	739	3395
	1992–1993	3.5	2.3	1009	336	1948
	1993–1994	3.4	1.8	749	280	1744
	Percent Decrease[1]		87	94	95	91

[1] 1989–1990 compared to current (1993–1994) annual mean value.

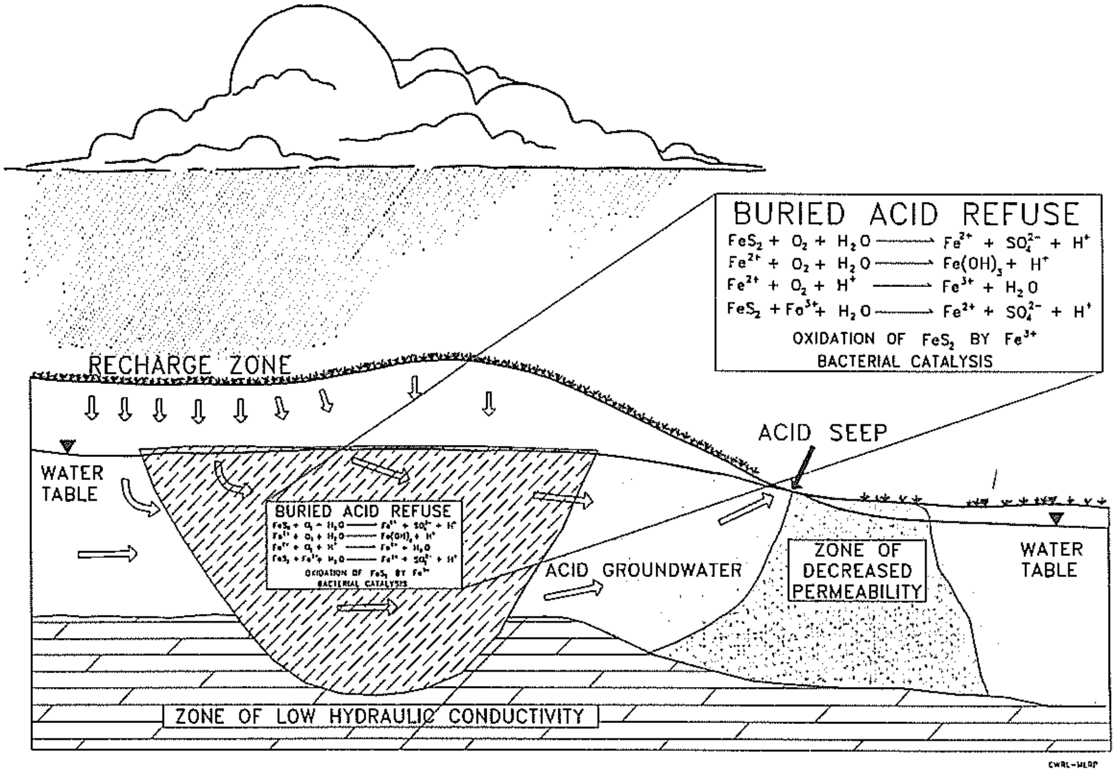

Figure 1. Hydrogeochemical factors affecting acid seep generation in buried refuse areas.

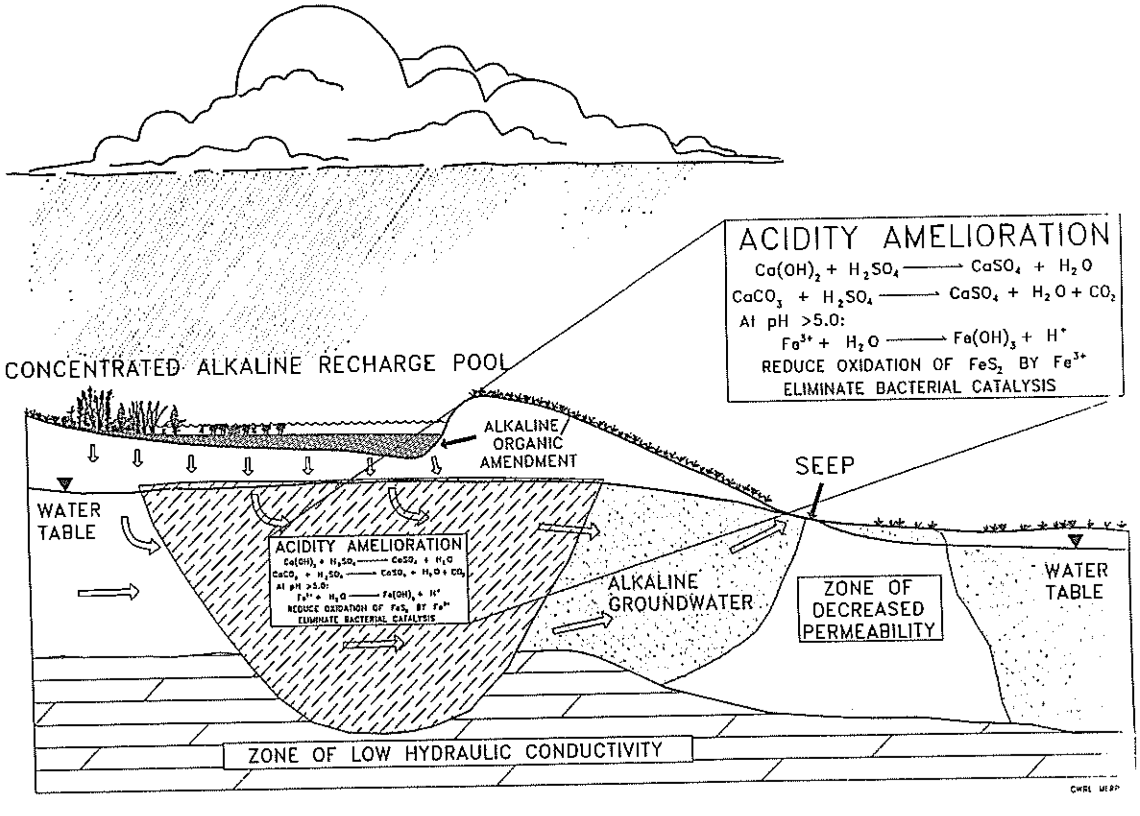

Figure 2. Concentrated alkaline recharge pool approach for abatement of acid seeps generated by buried refuse areas.

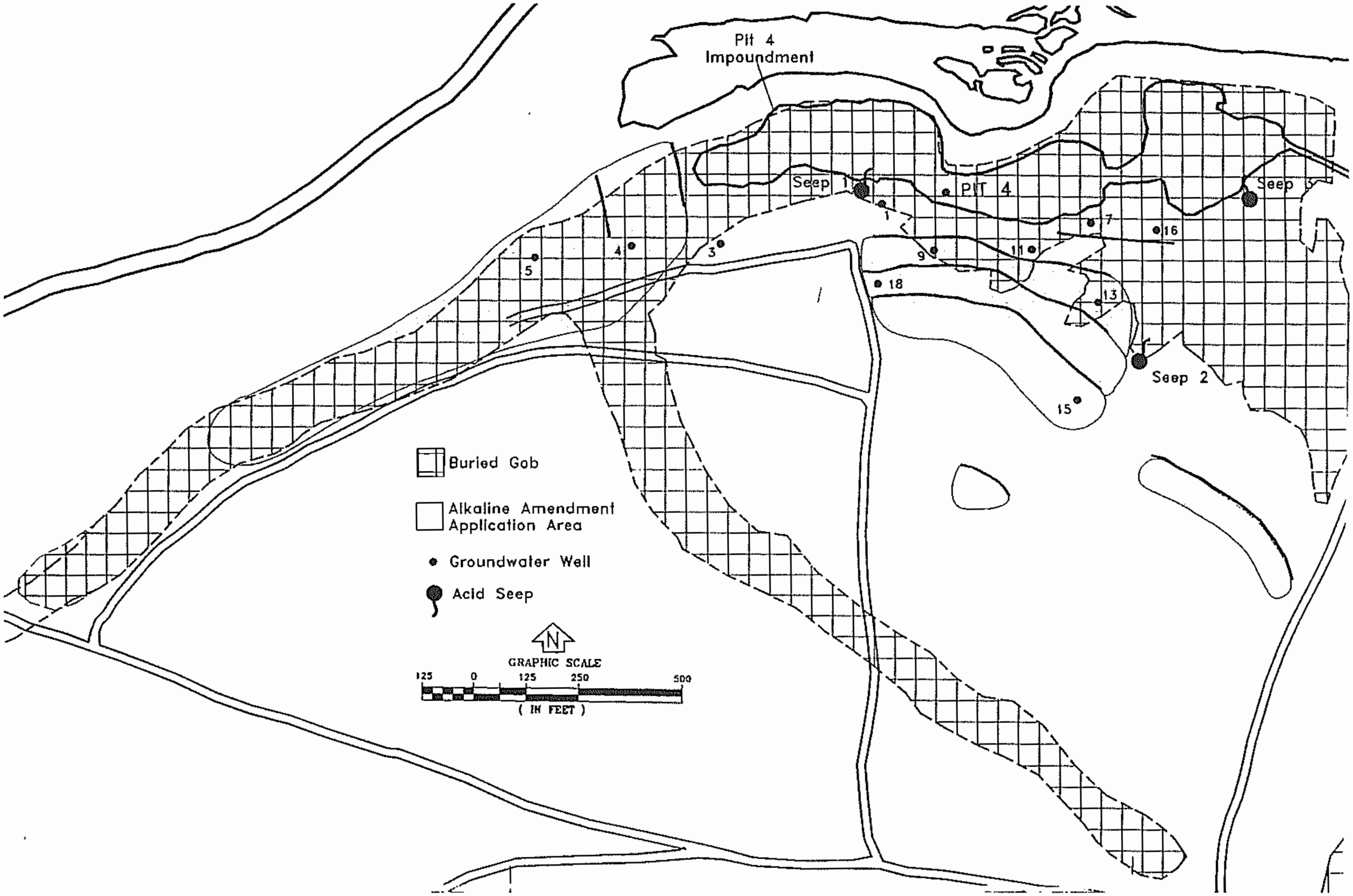

Figure 3. Peabody Will Scarlet Mine Pit 4 acid seep abatement demonstration area.

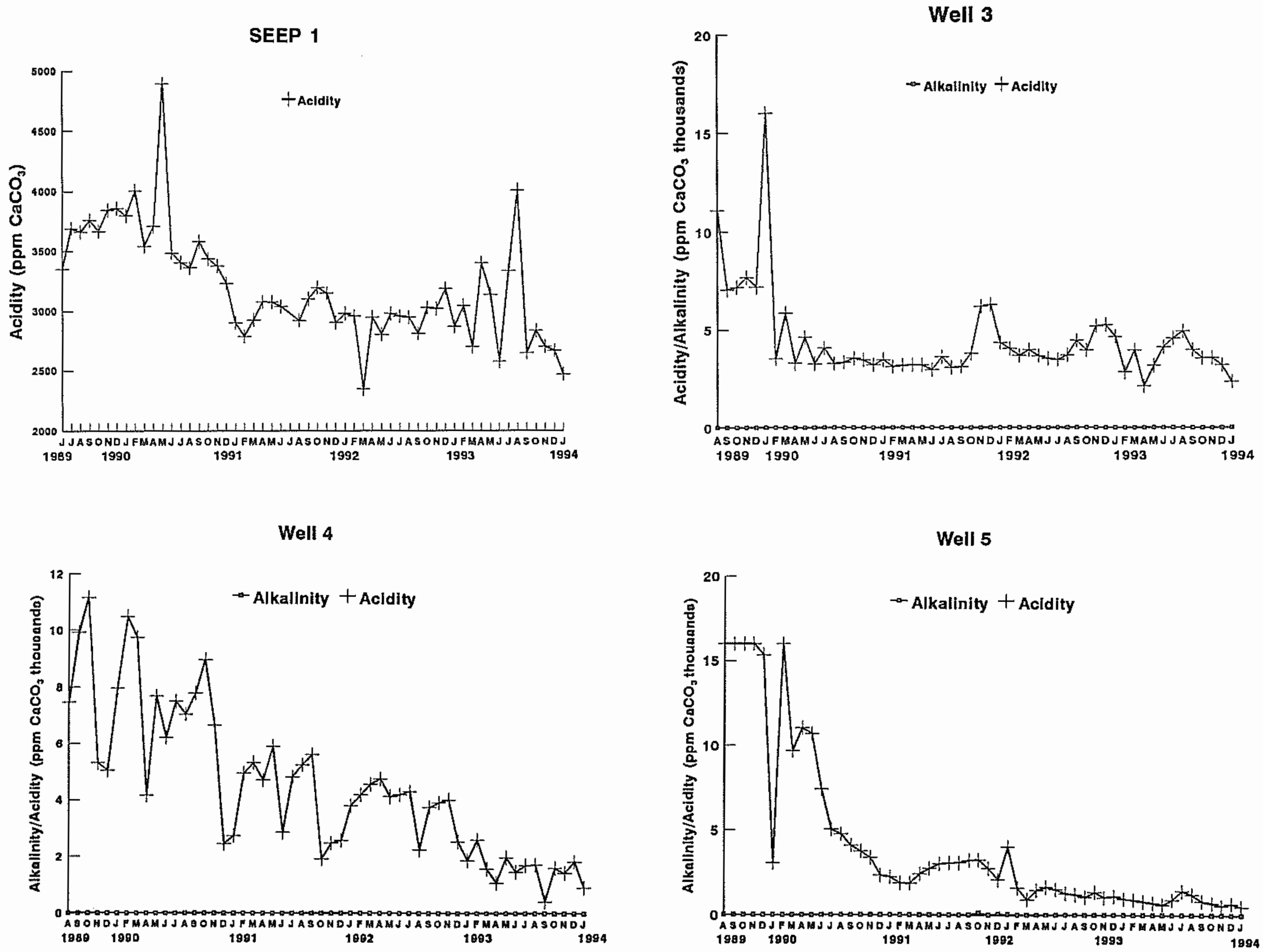

Figure 4. Peabody Will Scarlet Old Works Pit 4 alkaline (alkaline amendment initiated fall 1989) recharge area. Acidity trends for recharge zone wells (3, 4, 5) and primary seep (Seep 1).