Ohio Department of Natural Resources
Division of Mineral Resources Management

Memo

To: AML and Permitting Staff

From: Mike Sponsler *Mike*

CC:

Date: December 15, 2005

Re: Acid and Toxic Materials

Congratulations and good job on the recovery of acid mine impaired streams that we are seeing as a result of your efforts. This is truly a milestone in Ohio's environmental history and all of you are recognized and commended for the results you have produced. It is truly heartening to see fish repopulating previously dead waters.

As we move towards completion of some of our major acid mine discharge treatment projects, I want to advise everyone that I want us to turn more attention towards methods that will address the acid production at the source. As you are all aware, treatment has a finite life and we are merely buying time until we can come up with more permanent source treatment methods. So the time is now to begin development of source treatment solutions. The following is your directive in moving forward on acid mine drainage projects and regulatory permits with toxic material reclamation plans.

Research and past practices have shown even 4 feet of soil cover will acidify over time. Best management practices call for acid-producing materials to be treated with a neutralizing agent at a rate that meets the maximum net neutralization potential of the material to be treated prior to cover. If split applications of the neutralizer is necessary for effective treatment, projects and permits should be designed to require a split year application process where the site is planted with a cover crop, hot spots identified and supplementally treated, followed by the next split application treatment and replanting of the entire site prior to any placement of cover. This may take 2-3 cycles over 2-3 years, but is time well spent over the long term. In my judgment science has shown, covering toxic material without first neutralizing will be ineffective over time and therefore is not an effective long-term usage of dollars or our

regulatory authority. Frankly, treating is probably more important than cover, even 4 feet is a temporary solution. I also consider clay liners or caps as also having only temporary efficacy, because over time caps will deteriorate and leak. When they leak, the entire covered toxic area is jeopardized. Moreover, restricting infiltration causes its own problems with increased runoff and root restrictions.

Past research and practices have shown that it is also important to recognize on older refuse areas that aging and weathering reduces the amount of acidity in the surface of refuse materials. Substantial money can be saved by minimizing the regrading of refuse material, because less alkaline enhancement will be needed by taking advantage of the aging and weather process that has already reduced the surface acidity in the refuse. Savings in equipment time will also be realized. These savings can then be applied toward additional alkaline material application.

Research and past practices have also shown that alkaline recharge pools are an effective means of treating the source of acid producing materials. The steel slag leach pools are representative of this approach. Prior to any further designs of discharge treatment plans, a full evaluation of source treatment options with recommendations for the reclamation shall be prepared and provided to me for review and approval.

See the attached articles for more information. There is also a large library on coal research at Southern Illinois University where much more data and information can be reviewed. It can be accessed at http://www.siu.edu/~wildlife/research/reclaim.html. I look forward to our new innovations in this area. Thanks.

If you should require additional information, do not hesitate to contact me.

Proceedings, 1987 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation
University of Kentucky, Lexington, Kentucky, December 7-11, 1987

Coarse Refuse: Alkaline Enhancement and Reduced Soil Cover — An Effective Reclamation Alternative

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Abstract. Current coarse refuse reclamation requires 4-foot of soil cover for potentially acid-producing materials. While soil covering provides a substrate for vegetation establishment, this "out-of-sight, out-of-mind" reclamation approach does not address the establishment of a long-term acid-base equilibrium in the oxidizing refuse surface zone (≤30") beneath the soil cover. While soil cover has been credited with inhibition of oxygen and water infiltration, soil cover alone does not necessarily preclude acid generation as evidenced by post-reclamation acid seeps. Recognizing that effective reclamation of potentially acid producing materials should achieve more than provide a thin soil veneer for plant establishment, the Cooperative Wildlife Research Laboratory of Southern Illinois University at Carbondale initiated a 5-acre reclamation demonstration in 1980 to evaluate the relative effectiveness of soil cover depths (0, 1', 2', 3', 4') and limestone amendment rates (0, 15, 50, 150 tons $CaCO_3$ eq/1,000 tons) as a long-term solution to upward acid diffusion in soil covered refuse areas. After 6 years, annual monitoring of soil cover and the soil/refuse interface indicated that limestone amendment (equivalent to the maximum potential acidity based on pyritic sulfur values of unoxidized refuse) is necessary to prevent acidification of the soil cover, the soil/refuse interface, and the surface zone of oxidizing refuse. Without sufficient limestone amendment as much as 12 to 18 inches of the overlying soil cover is lost due to acidification. Supplemental limestone amendment provides a "treat" and/or cover alternative to the four-foot cover requirement. Upslope alkaline loading of the refuse acid-base system offers several practical advantages including: 1) increased rooting depth, 2) physical (root) binding of soil cover veneers to amended nonacid refuse substrates, 3) alkaline flushing of the reactive surface refuse zone, 4) establishment of an alkaline soil environment not conducive to bacterial catalysis and acid formation by *Thiobacillus ferrooxidans*, 5) prevention of soil cover acidification, and 6) long-term maintenance of favorable acid-base equilibrium in the reactive refuse zone. Following our Laboratory's pilot study, full-scale alkaline enhancement alternatives for coarse refuse reclamation have been implemented. These include limestone amendment only (@ 150-200 tons $CaCO_3$ eq/1,000 tons) for a pre-law (ca. 1971) 50-acre refuse area, and planned variances for limestone amendment (@ ~40-80 tons $CaCO_3$ eq/1,000 tons) with reduced soil cover on 2 post-law sites.

When properly implemented, alkaline enhancement can offer a practical, cost-effective alternative to the 4-foot cover requirement, as the cause of acid generation is treated rather than simply covered.

Introduction

The Surface Mining Control and Reclamation Act of 1977 (P.L. 95-87) requires toxic coarse refuse materials (gob) be covered with 4 feet of nontoxic material to prevent oxidation of acid-forming materials and to allow for effective vegetative stabilization. However, this "out-of-sight, out-of-mind" reclamation approach does not address the establishment of a long-term acid-base equilibrium in the oxidizing refuse surface zone (<30") beneath the soil cover; upward acid diffusion and acid seeps result in many instances. As large volumes of soil are needed to cover extensive refuse piles, economic and environmental consequences of obtaining soil cover can be severe. Current costs of covering a refuse area with 4 feet of soil in the midwest range from approximately $16,000 to $20,000 per acre.

Although a nontoxic root medium is essential for successful vegetation establishment, one study noted no difference in vigor of vegetation growing on soil cover depths ranging from 9 inches to 4 feet.[1] Another found 1-foot and 2-foot soil cover depths to be no less effective than a 3-foot cover in altering quality of runoff from an abandoned deep mine refuse area in Illinois.[2] Several studies have identified the potential of establishing vegetative cover on mine refuse without the use of a soil cover.[3,4,5,6,7,8,9]

Experimental plots established by the Illinois Department of Mines and Minerals (IDMM) Division of Land Reclamation demonstrated that coarse refuse could be directly limed and seeded.[10] Nawrot et al investigated physical and chemical factors influencing revegetation potential of coarse refuse at 508 inactive mine sites in Illinois, identifying reclamation alternatives to required grading and soil covering.[11] Documentation of factors affecting the colonization of inactive refuse areas by native vegetation further illustrated that with time, mine wastes can be transformed into mine soils.[12,13]

Based upon subsequent evaluation of the IDMM experimental plots, the Cooperative Wildlife Research Laboratory (CWRL) of Southern Illinois University at Carbondale initiated a reclamation demonstration in 1980 with Monterey Coal Company (MCC) to evaluate the relative effectiveness of liming rates and soil cover depths of coarse refuse. Effective reclamation principles, supported by data from the CWRL/MCC pilot study, have since been used in implementing full-scale alkaline enhancement alternatives for coarse refuse reclamation.

CWRL/MCC Pilot Study

Methods

Soil cover depths of 0, 1, 2, 3, and 4 feet were established over lime rates of 0, 15, 50, and 150 tons/acre on a 5.0-acre plot (Figure 1). The 15 tons/acre rate was to neutralize immediate acidity; the 150 tons/acre rate was based on maximum total potential acidity values (@ 31 tons/1% pyritic sulfur). Amendment application, soil covering, final grading, and seeding was completed during August 1980.

Limestone amendments (dry applied) utilized agricultural grade limestone with a calcium carbonate equivalent of 83.4 percent (Figure 2). Amendments applied in the 150 and 50 tons/acre treatments were disced to a 6-inch depth. The 15 tons/acre rate was surface applied with no incorporation.

Soil cover was initiated immediately after limestone application. After final rough grading, 2 tons/acre limestone was applied to all soil cover depths. Each

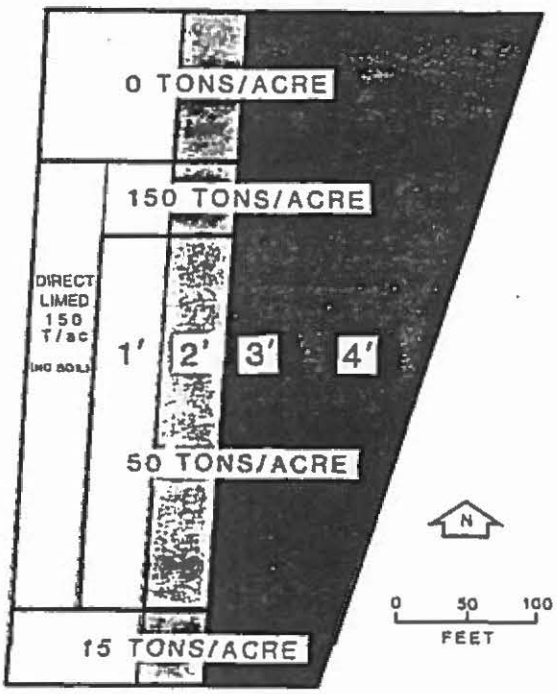

Figure 1. Limestone application rates and soil cover depths of coarse refuse plots established at Monterey Coal Company No. 1 Mine Refuse Area No. 1, August 1980.

plot treatment was then fertilized, broadcast seeded, and planted with tree seedlings (Table 1).

To determine relative effectiveness of soil cover depths and limestone amendment rates, soil/refuse samples were collected annually from October 1981 to January 1986. Samples included 0-6 inches of soil cover above refuse (amended and unamended) and 0-6 inches of underlying refuse for each cover depth and limestone rate. Samples were collected using a 4-inch bucket auger, bagged, and returned to the laboratory for analysis of pH and conductivity by standard methods.[14,15] A quantitative evaluation of vegetative cover density and vigor was made October 1981.

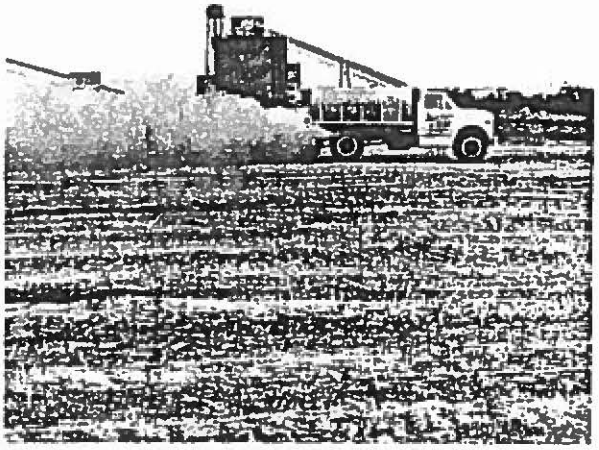

Figure 2. Agricultural limestone application on coarse refuse plots at Monterey Coal Company No. 1 Mine, Macoupin County, Illinois.

Results and Discussion

Evaluation of sample analyses for limestone-soil cover treatments indicated the value of limestone neutralization based on maximum total potential acidity values (i.e., 150 tons/acre) prior to soil cover application. Regardless of soil cover depth, the 150 tons/acre rate prevented upward acid diffusion and acidification of the overlying soil cover (Figures 3 and 4). Soil cover depth did not appear to influence the degree of soil acidity above treated refuse. Similarly, refuse amended with limestone at 150 tons/acre maintained near neutral conditions (Figures 5 and 6) at 0-6 inches; soil cover depth was not a factor. In addition to prevention of upward acid diffusion, the 150 tons/acre rate also extended the effective rooting depth in each soil cover treatment at least 12 inches (6+ inches of overlying soil cover plus 6+ inches of amended refuse), increasing the total effectiveness of soil cover. Acidification of soil cover (2-foot and 3-foot depths) over coarse refuse which had been insufficiently amended with limestone (15 tons/acre) was recorded at a 40-acre gob pile in southern Illinois.[16] Soil cover immediately above (0-6 inches) refuse (refuse pH = 3.1-3.3) had pH values of 3.2 to 3.5; soil cover 1 foot above refuse had a pH of 4.2.

Overall ground cover density of the CWRL/MCC plots was characterized as between 80 to 100 percent with excellent cover and good diversity associated with all soil cover depths. Plant vigor was also excellent with no discernible differences

Table 1. Seeding rates and number of tree seedlings planted on Monterey Coal Company No. 1 Mine Refuse Area No. 1, 1980-81[a].

Species	Seeding Rate (lbs/ac)	No. of Tree Seedlings
Rye Grain	40.0	
K-31 Fescue	30.0	
Smooth Brome	22.5	
Perennial Rye	5.0	
Blackwell Switchgrass	1.25 (3.0)	
Birdsfoot Trefoil	1.25 (3.0)	
Korean Lespedeza	2.25	
Yellow Sweet Clover	5.0	
Weeping Lovegrass	(4.0) (0' soil cover only)	
Black Locust		175
Autumn Olive		100
Osage Orange		225

[a]Bulk blended granular fertilizer (46-0-0, 18-46-0, 0-0-60) at rate of 75 lbs/acre @ NPK surface applied prior to final seedbed preparation. Grasses and legumes broadcast seeded Fall 1980 except where () denotes supplemental seeding April 1981. Straw mulch applied Fall 1980. Tree seedlings planted March 1981. Fertilizer top dressed June 1981 at rate of 65 lbs/acre @ NPK.

related to cover depths of limestone treatments.

Ground cover density on the limestone-no soil cover plot was estimated at 70 percent. Plant vigor was noticeably reduced due to drought induced stress associated with the shallow (6 inch) rooting depth in the amended refuse.

Black locust (Robinia pseudoacacia) reflected greatest survival (72 percent) of woody species. Growth after 6 months was quite good with a mean height of 5.4 feet recorded for all soil cover depths over the 150 tons/acre limestone amended refuse. A 50 percent reduction in mean height was recorded for black locust planted on the limestone-no soil cover plot. The shallow rooting depth of the amended refuse precluded deep rooting and consequently contributed to poorer growth and survival due to drought associated stress.

Principles of Alkaline Enhancement

The ability of limestone to neutralize acid soils has been appreciated by agricultural communities since the time of the Roman Empire.[17] However, its effectiveness in mine soils/refuse acid source abatement has been largely under-utilized although the potential has been long recognized.[18,19] Specific mechanisms and details of acid mine drainage (AMD) formation have been (and continue to be) topics of numerous studies, reports, and symposia at the cost of sometimes overlooking the basic tenets of acid soils formation and reclamation. The results have been too many dust-gathering publications and not enough green acres.

Reclamation with alkaline enhancement is based on a few well-known principles. At the risk of over-simplification, they are: 1) coal refuse materials contain iron disulfide (pyrite); 2) pyrite oxidizes generating sulfuric acid and ferrous sulfate (AMD); 3) refuse materials "become acid" when rates of acid formation exceed neutralization capacities (acid-base imbalance) and, 4) acid-base balance is maintained or restored with the addition of alkalinity (limestone). Limestone application based on acid-base balances (as determined by pyritic sulfur values) of both surface and deep materials neutralizes immediate

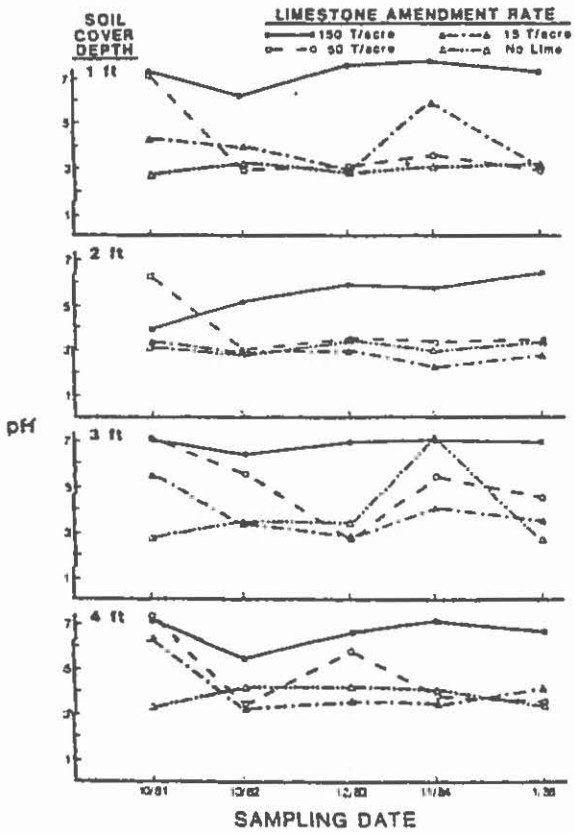

Figure 3. Soil cover pH 0-6" above coarse refuse at varying limestone amendment rates and soil cover depths, Monterey Coal Company No. 1 Mine.

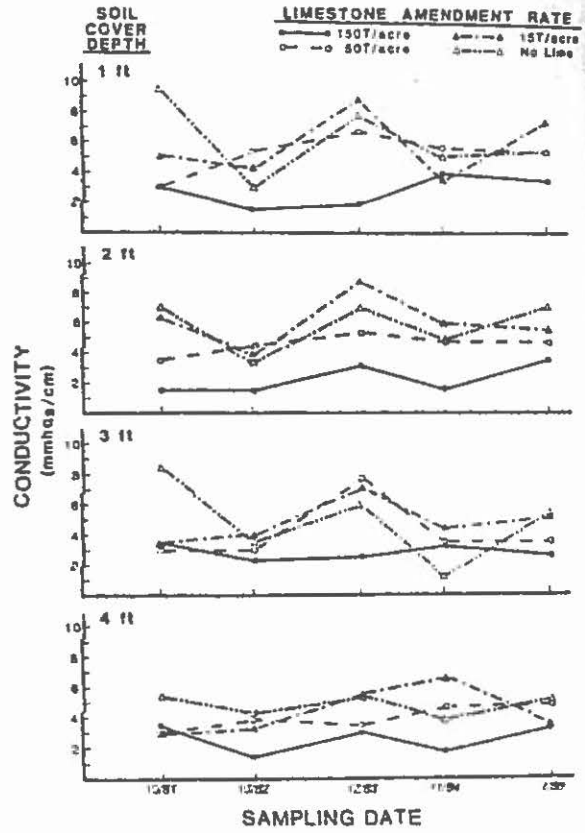

Figure 4. Conductivity of soil cover 0-6" above coarse refuse at varying limestone amendment rates and soil cover depths, Monterey Coal Company No. 1 Mine.

acidity, provides for buffering against future acid generation, and as demonstrated by the CWRL/MCC study, protects soil cover from upward acidification.

In order for limestone to be effective, application rates must be based on maximum potential acidity values as oxidation of pyrite due to aging and weathering is inevitable. "Over-treatment" with limestone flushes surface materials and allows for long-term infiltration of alkalinity.[20] Further, maintenance of an alkaline soil environment inhibits bacterial (*Thiobacillus ferrooxidans*) activity.[21] Limestone application/incorporation at the surface also limits iron-coating or armoring of limestone particles as the alkalinity is placed above the acid material.[22] Directly seeded plots on coarse refuse following limestone and fertilizer applications by IDMM in 1973 have shown no indications of reacidification due to armoring nearly 15 years later.

Soil covering may retard oxygen diffusion to the refuse, but does not guarantee inhibition of oxidation and subsequent acid production.[23] Likewise, attempting to remove and completely exclude *Thiobacillus ferrooxidans* from pyrite as a means to inhibit bacterial oxidation has not been demonstrated to be an effective long-term solution. It should therefore be recognized that successful reclamation addresses the source and not the symptoms, nor the catalysts of acid formation. Limestone neutralization of acid refuse is such a source-directed reclamation approach.

Current Reclamation Projects

Our demonstrated success of alkaline enhancement in coarse refuse reclamation has been instrumental in planning and implementing full-scale reclamation alternatives in Illinois. All projects emphasize limestone amendment. The Peabody Will Scarlet site (outlined below) represents successful reclamation of coarse refuse without soil cover.

Peabody Coal Company Will Scarlet Mine

Reclamation of a 50-acre coarse refuse pile at the Peabody Will Scarlet Mine (Williamson County, Illinois) was based on the principles of refuse aging and weathering as well as the test plots pre-

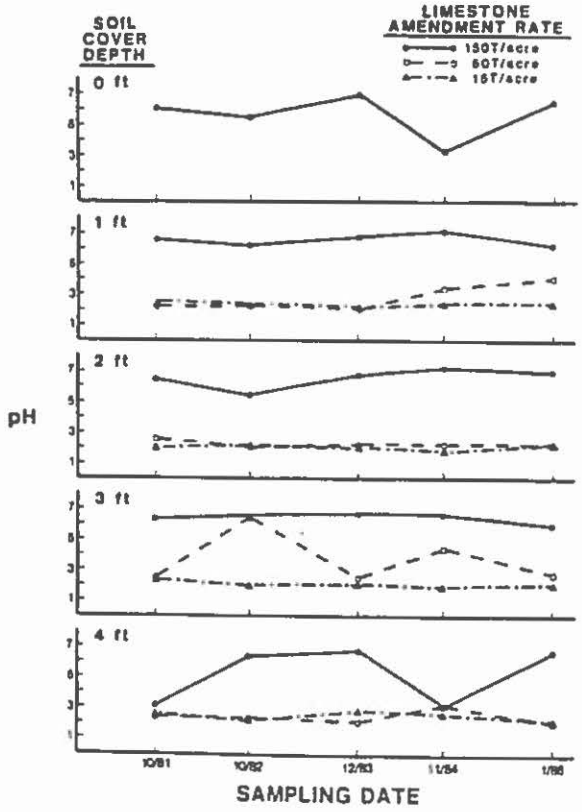

Figure 5. pH of amended coarse refuse (0-6") at varying limestone amendment rates and soil cover depths, Monterey Coal Company No. 1 Mine.

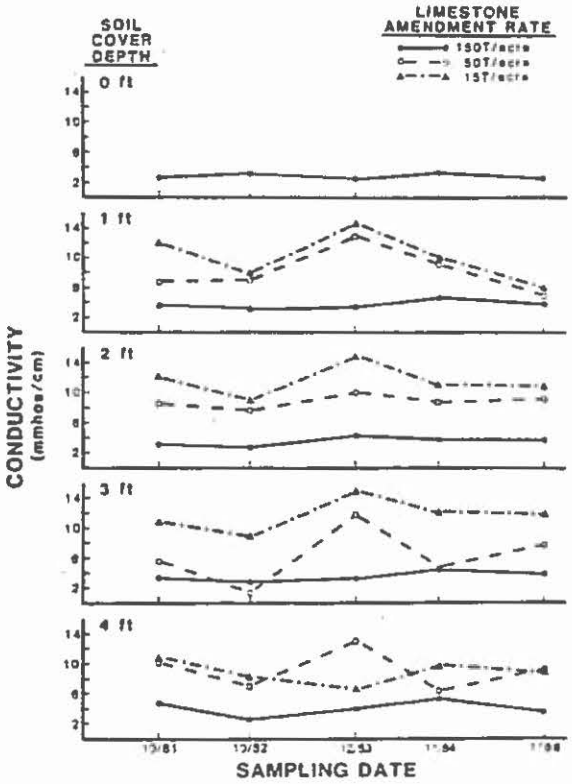

Figure 6. Conductivity of amended coarse refuse (0-6") at varying limestone amendment rates and soil cover depths, Monterey Coal Company No. 1 Mine.

viously established there in 1973 by IDMM.[10,11,24] Reexamination of the experimental plots by CWRL personnel in 1984 indicated the feasibility of direct liming and seeding as a cost-effective alternative to soil cover. Sampling of plot refuse materials reflected the physical and chemical effects of more than 12 years of aging and weathering. Potential acidity had been reduced from >200 tons $CaCO_3$ eq/1,000 tons to <8 tons $CaCO_3$ eq/1,000 tons in the weathered refuse surface. Additional effects of aging and leaching were evident in the significant reduction of extractable aluminum in surface (65 ppm) as compared to unweathered subsurface materials (496 ppm). Leaching of metallic ions from surface materials also contributed to a significant reduction in salinity (3.0 mmhos/cm @ 0-6 inches; 28.0 mmhos/cm @ >12 inches). Physical changes in refuse materials were also illustrated by the reduction of the sand size soil fraction, and increase of clay fraction resulting from weathering of shales in the surface zone.

To establish vegetation directly in the weathered surface zone, neutralization of immediate acidity and enhancement of neutralization potential was necessary to offset any future oxidation of untreated pyritic sulfur. In addition to amending existing acid conditions and providing for neutralization of future oxidation, "overtreatment" of the weathered zone with excess agricultural limestone was designed to provide long-term excess alkalinity for the surface groundwater system. Approximately 35-40 tons/acre of agricultural limestone were incorporated September 1984. After discing, furrows (24-30 inches deep) were prepared in the coarse refuse using a modified cable trencher and filled with agricultural limestone (40-50 tons $CaCO_3$ eq/1,000 tons). Agricultural limestone was *again surface applied (50 tons/acre) following* deep ripping. After discing, treated areas were fertilized and seeded with winter rye (Secale cereale).

In the spring of 1985, reclamation continued with the establishment of 31,000 black locust seedlings. Examination of trees in September 1985 indicated greater than 70 percent survival in areas characterized by the most extensively weathered refuse materials. Assessment of second-year locust growth in September 1986 showed greater than 65 percent survival with an average height gain of 1.4 feet (Figure 7). Emergence of sweetclover (Melilotus spp.) and red clover (Trifolium pratense) in summer and fall 1985 supplemented ground cover and added to organic matter previously provided by the rye cover crop.

Annual follow-up sampling has reflected maintenance of non-acid ($\bar{X}$ pH = 6.9, aluminum <5.0 ppm) conditions in amended surface zones. Excess neutralization potential *(>150 tons $CaCO_3$ eq/1,000 tons) of* surface material has also begun alkaline flushing to the underlying unweathered zone to ameliorate acid soil conditions; pre-

Figure 7. Second-year growth of black locust seedlings planted directly into limestone-amended coarse refuse at Peabody Will Scarlet Mine, Williamson County, Illinois.

reclamation mean pH of 2.2 increased to 3.6 by September 1986.

Active Mine Refuse

Following the success of the CWRL/MCC pilot study and full-scale Peabody Will Scarlet direct lime/seeding project, CWRL became involved with Illinois coal industry and regulatory representatives to address reclamation alternatives for two active deep mine refuse sites. Recognizing that supplemental sources of alkalinity were necessary for effective reclamation, field sampling was initiated to determine neutralization amendment requirements. Analyses of the coarse refuse materials reflected regional variability in composition of coal, shale, rock, roof, and floor materials, with one site (south-central Illinois) requiring 80 tons $CaCO_3$ eq/1,000 tons of limestone and the other (southeastern Illinois) requiring 40 tons $CaCO_3$ eq/1,000 tons of limestone to satisfy total potential acidity values of fresh refuse. Further characterization identified treat and/or cover (i.e., limestone amendment and <4-foot soil cover) alternatives specific for each site. Final plans have been developed for full-scale reclamation and submitted (spring/summer 1987) to IDMM for consideration.

Recommendations And Conclusions

Limestone amendment has been demonstrated to be an effective, economical, and necessary part of coarse refuse reclamation. The importance of aging and weathering, as demonstrated at the Peabody Will Scarlet site, must also be recognized. Based upon our experience, we recommend the following reclamation considerations: 1) if possible, allow refuse to undergo several cycles of aging and weathering to reduce reactive pyrite sulfur levels (stabilize acid-base balance) and reclamation costs; 2) determine acid-base balance of the system (recognize that nearly all pyrite will oxidize in surface zones) through intensive site characterization and calculate maximum limestone amounts needed to overload the system with alkalinity; 3) use fine grade agricultural limestone (≥30% finer than 60 mesh) as it provides a good mix of immediately reactive and slow release particle sizes (if refuse material has high acute acidity values, a finer grade of limestone may be used in the initial application or the system may be "overtreated" with agricultural limestone); and, 4) apply and incorporate (disc, deep rip) limestone in two to three split applications (e.g., 50 percent of total amount, followed by 30 percent, then 20 percent), allowing material to weather (6 months if possible) between applications.

Direct liming and seeding has potential for establishment of vegetative cover on well-weathered coarse refuse. However, soil covering may be necessary for recently inactive sites or disturbed sites in which the acid generation equilibrium has been disrupted due to reexposure of previously unoxidized pyritic materials. In these situations, the procedures outlined above should precede a soil cover necessary to provide additional rooting depth; however, less than 4 feet of cover will suffice as amended refuse serves as a non-acid substrate for vegetation allowing soil cover to be physically (root) bound to the refuse.

Effective coarse refuse reclamation depends largely on the nonphytotoxic rooting depth available to vegetation. Shallow root systems, as well as upward acid diffusion and subsequent reacidification inhibit successful vegetation establishment. Limestone amendment to neutralize immediate acidity and to provide buffering capacity against future oxidation or upward acidification creates a favorable rooting zone to ensure long-term reclamation success.

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

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

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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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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 (% CaCO3)
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 ≤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 ≤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.

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 (ppm$CaCO_3$)	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.

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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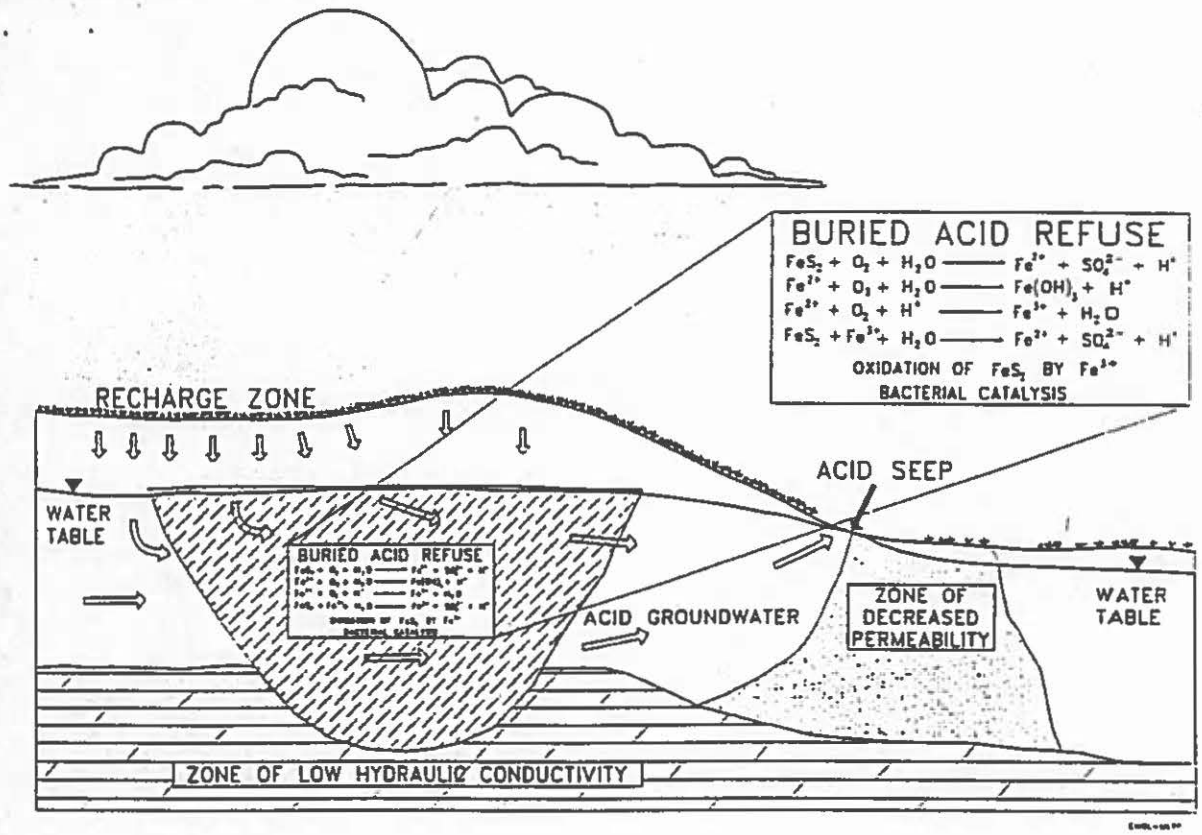


Figure 1. Hydrogeochemical factors affecting acid seep generation in buried refuse areas.

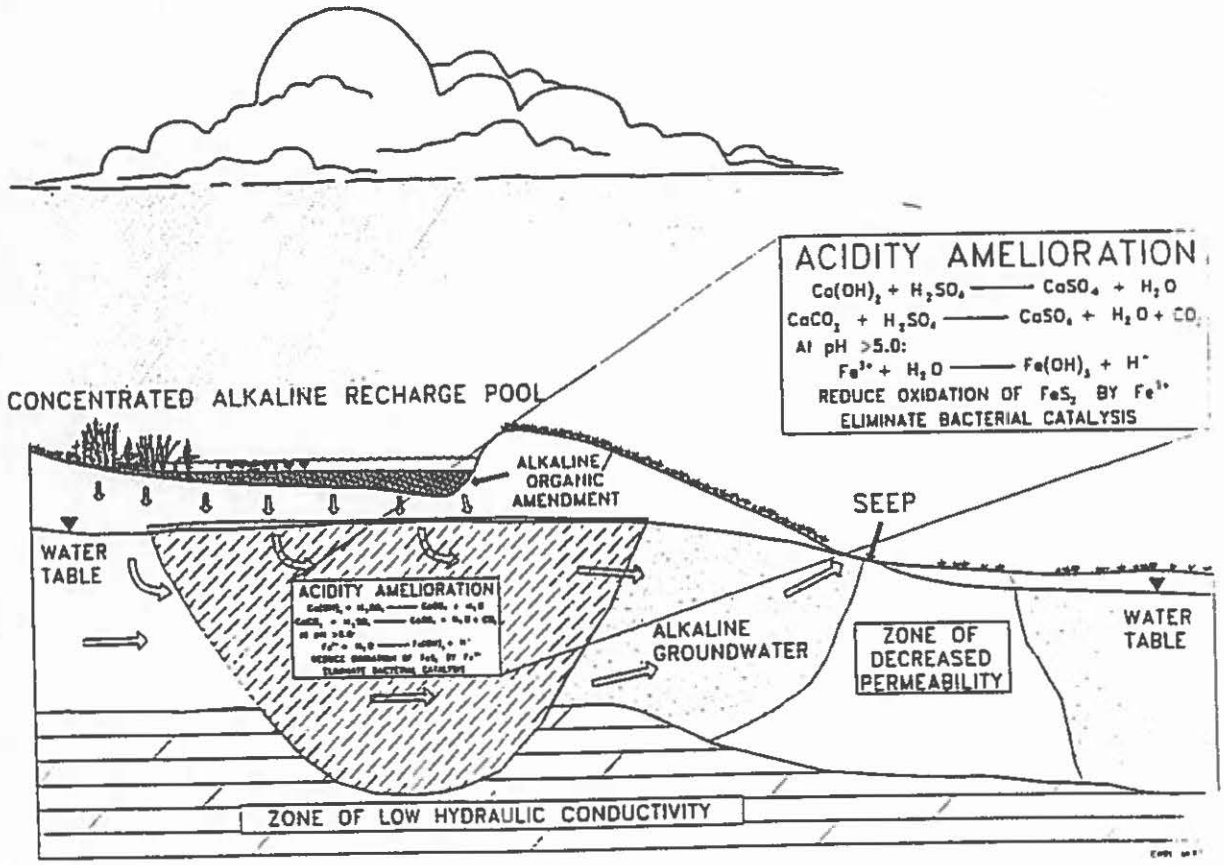
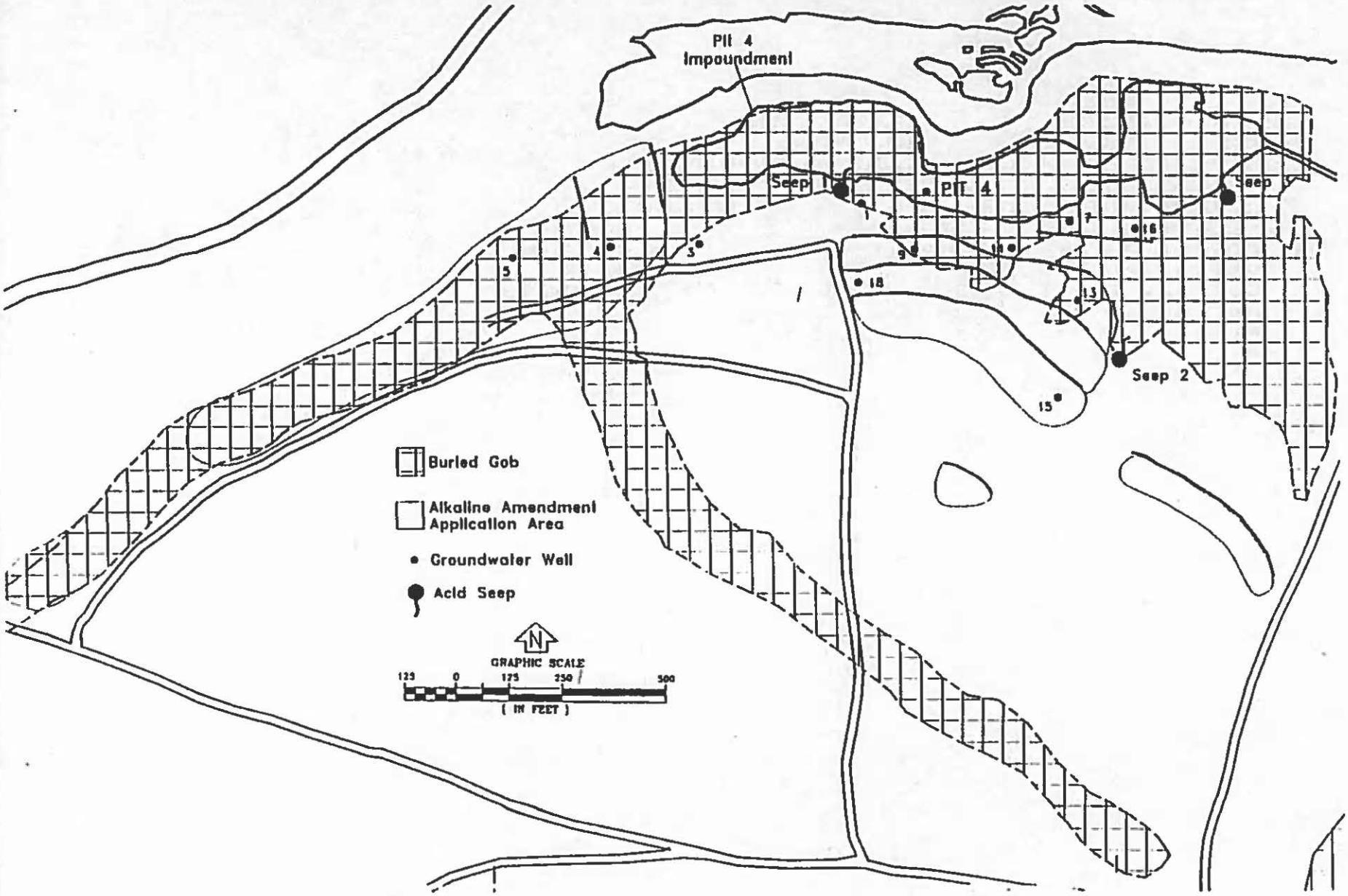
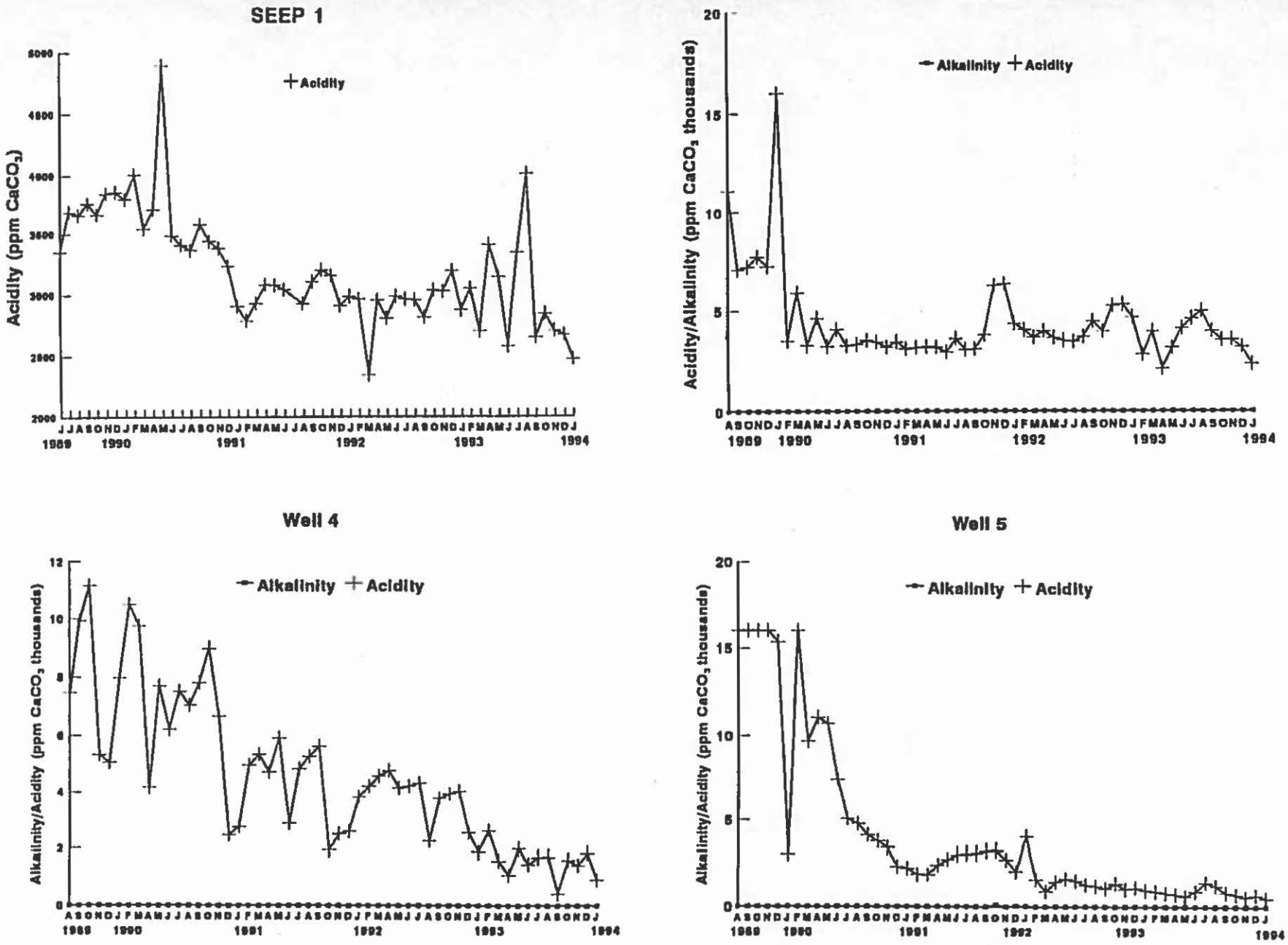


Figure 2. Concentrated alkaline recharge pool approach for abatement of acid seeps generated by buried refuse areas.



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



igure 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).