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 (% $CaCO_3$)
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 ≤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.

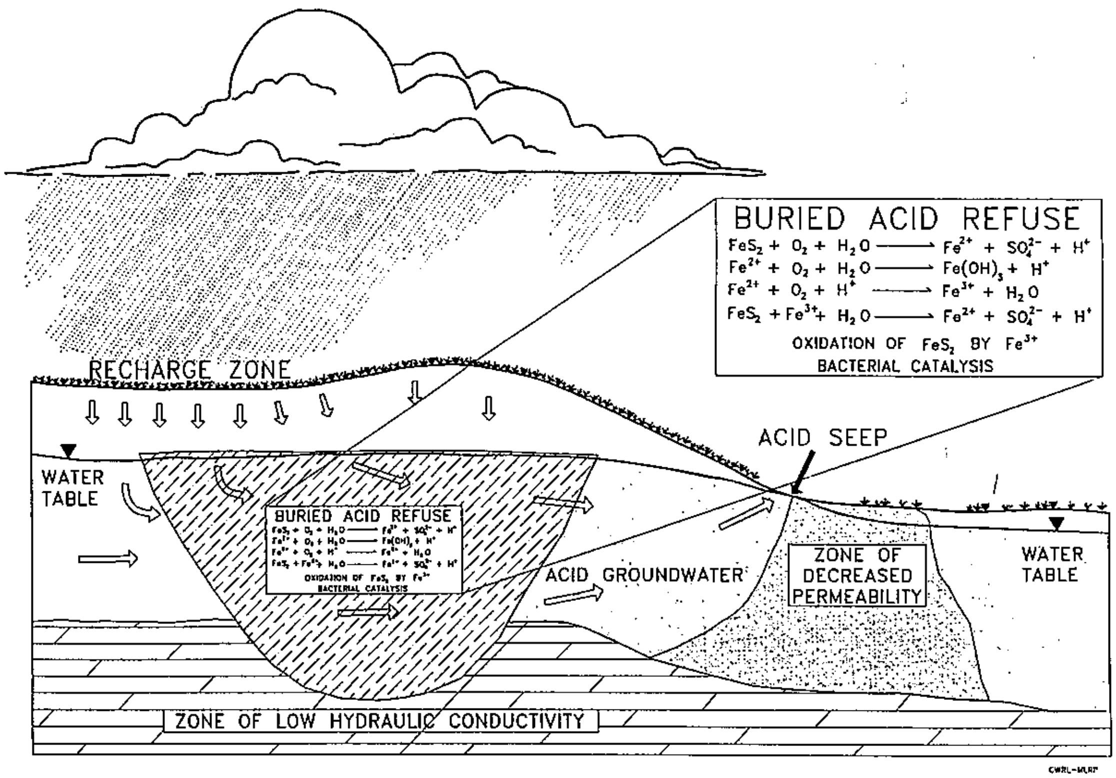

Figure 1. Hydrogeochemical factors affecting acid seep generation in buried refuse areas.

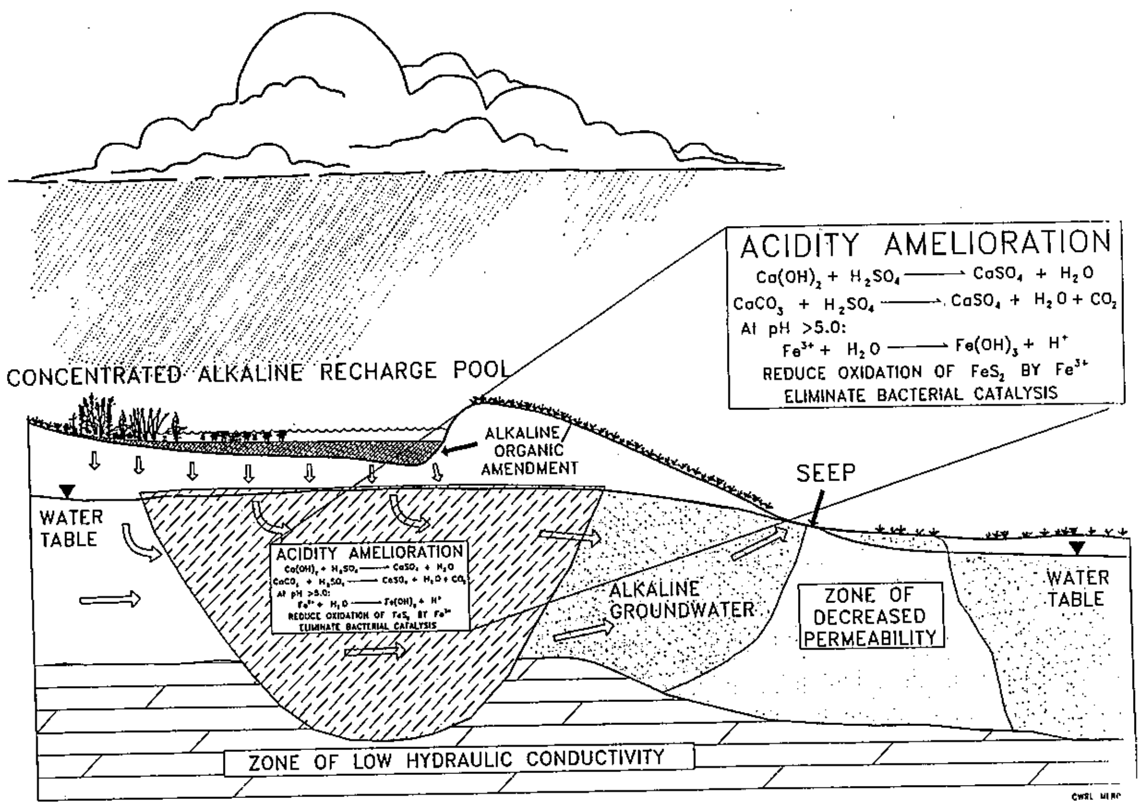

Figure 2. Concentrated alkaline recharge pool approach for abatement of acid seeps generated by buried refuse areas.

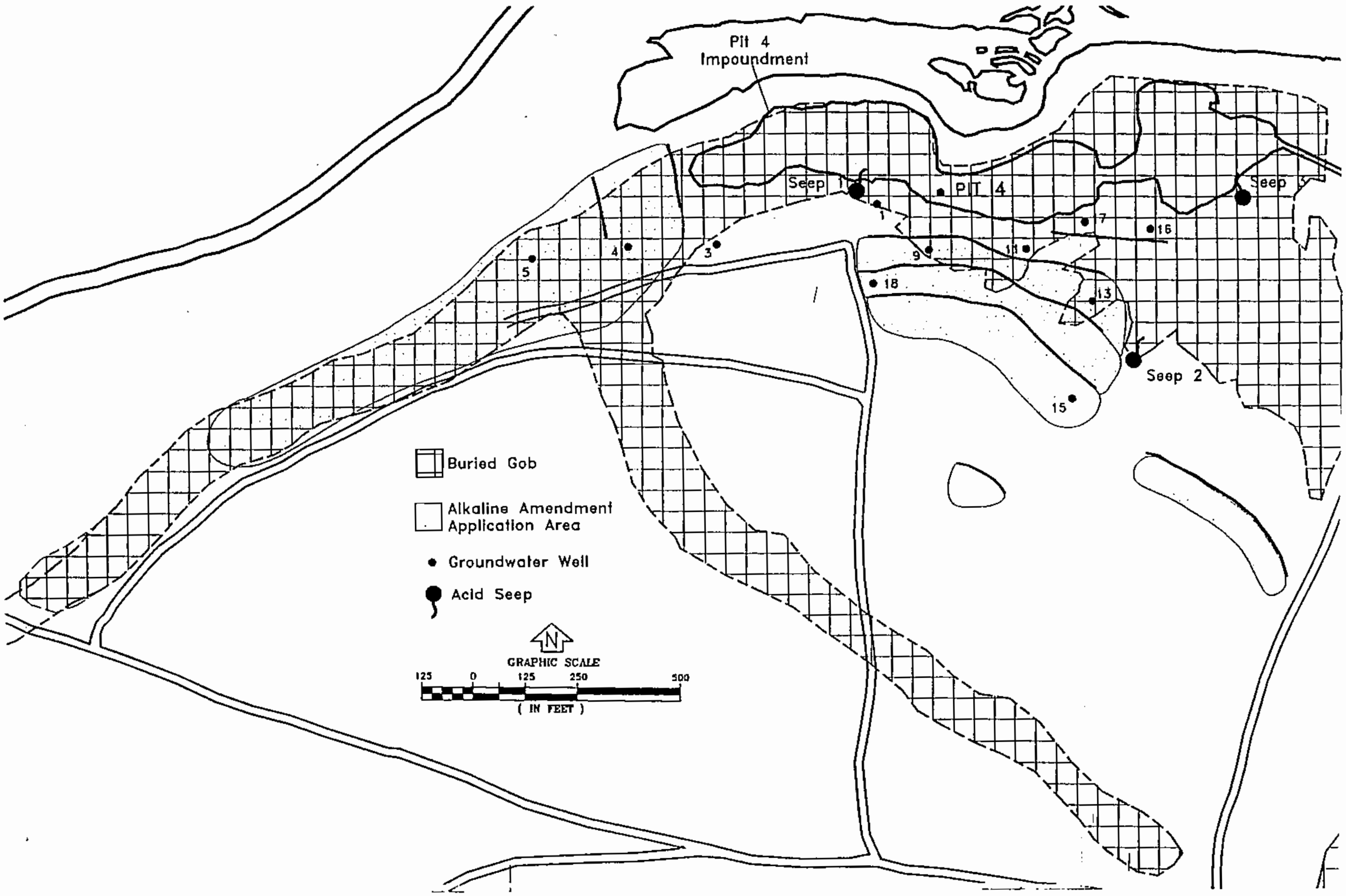

Figure 3. Peabody Will Scarlet Mine Pit 4 acid seep abatement demonstration area.

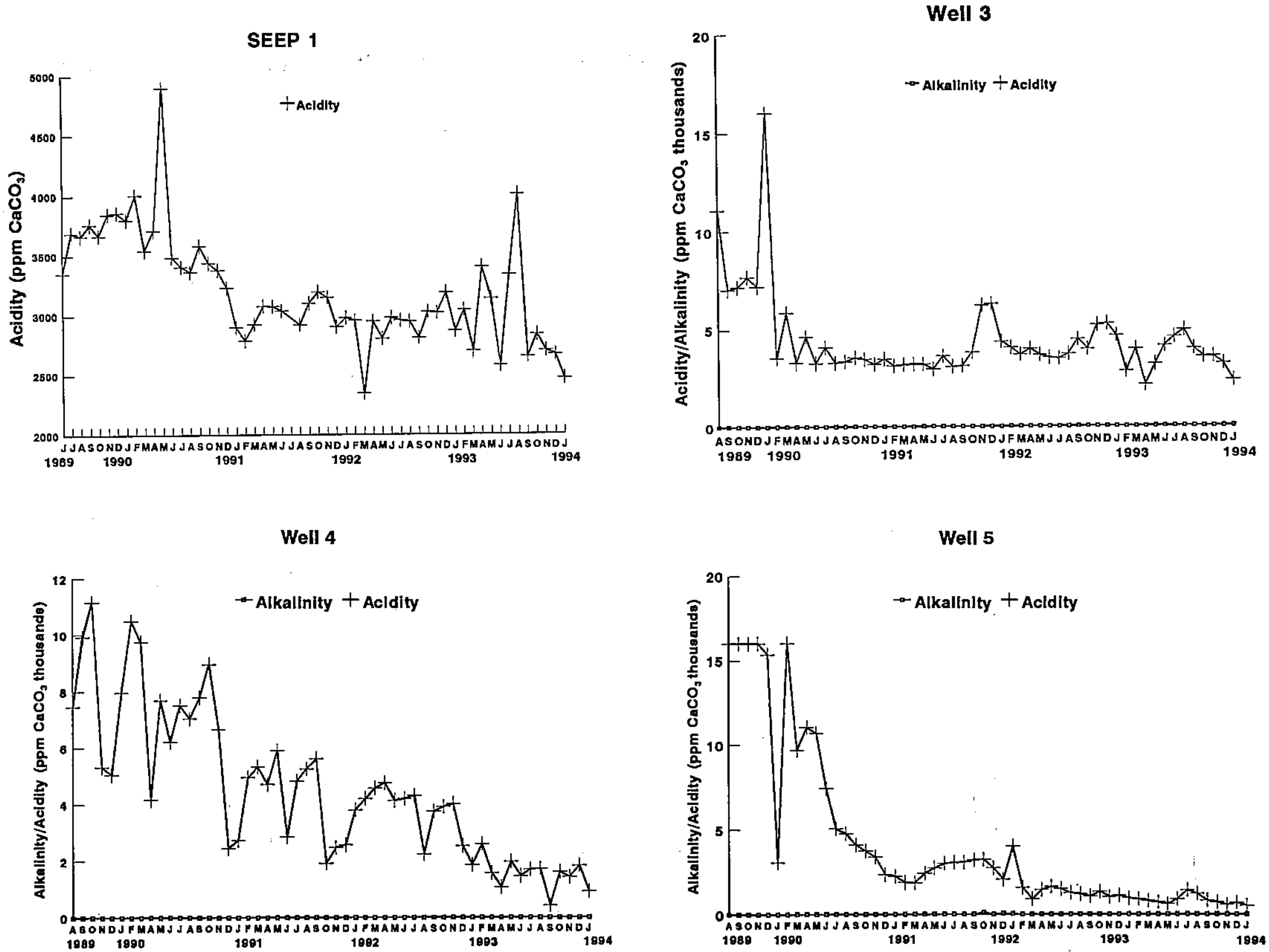

Figure 4. Peabody Will Scarlet Old Works Pit 4 alkaline (alkaline amendment initiated fall 1989) recharge area. Acidity trends for recharge zone wells (3, 4, 5) and primary seep (Seep 1).