ACID SOILS RECLAMATION: APPLYING THE PRINCIPLES

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Abstract. Abandoned mine land reclamation which only focnses on the adverse impacts of current conditions often overlooks and does not appreciate the vast chemical, physical, and vegetative improvements that occur as a result of the beneficial natural processes of aging, weathering, leaching, and plant colonization. Consequently, emphasis on "instant green" cosmetic reclamation by grading/covering rather than chemical/biological reclamation by nentralization/organic matter enhancement results in unnecessary grading and exposure of previously unoxidized pyritic soils. Working with nature to improve and build existing soils, enhance vegetative sncceesion, and treat the cause rather than tha symptom, represent basic principles of cost-effective pre-law reclamation. Such principles have been instrumental in implementing successful vegetation establishment practices at Peabody Coal's 2,400-acre Will Scarlet "Old Works" area in Williamson County, IL. The value of some of these cost-effective principles was initially evaluated during research/demonstration studies at Will Scarlet over two decades ago. Implementation of these principles and practices as opposed to "further research" has contributed to extensive abatement of acid conditions resulting in a $300,000/year reduction in AMD treatment costs. This paper provides an overview of AML reclamation practices at tha site of what has been called the "nation's worst" acid soils pre-law area. These include enhancing succession on acid spoils, direct vegetation of coarse refuse, and the alkaline capping and flooding of inactive slurry areas for wetland development and mine drainage treatment.

INTRODUCTION

Time and the associated benefits of weathering and aging are two basic reclamation components that money can't buy. Although the importance of aging and weathering has been recognized for decades, reclamation of acid soils in some AML projects often neglects this principle during unnecessary grading. The natural weathering and leaching of exposed soils and refuse represent an economically significant portion of geochemical reclamation that seldom is taken advantage of in design and engineering specifications.

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Unfortunately, cost-effective reclamation practices (i.e., minimal grading and enhancement of existing vegetation) are not always implemented due to other considerations such as: 1) pressure to spend all reclamation funds during one construction season or contract period, 2) the eagerness to try currently popular soil treatments or creative reclamation concepts, and 3) the misconception that more money always means better reclamation. Understandably, in some cases additional grading may be necessary to accommodate more intensive postreclamation development plans.

The gradual drifting away from basic reclamation practices of the past has ironically been a result of the abundance of State and Federal funds to research new ideas and implement new techniques. However, when researching new ideas or implementing new techniques does not include reviewing old ideas and improving old techniques, there has been and will be a shameful waste of time and money in duplicated effort. When current laboratory and small plot research projects continually conclude "further research is needed", there is little incentive for implementation of full-scale field demonstration practices. New research is perpetuated, while valuable past research is ignored.

Many past practices of acid soils reclamation have been based on simple principles:

1. **IF ITS NOT BROKE, DON'T FIX IT.**

2. **ACIDITY = LACK OF ALKALINITY.**

3. **TIME + LIMESTONE = GREEN.**

4. **TREAT THE SOURCE, NOT THE SYMPTOM.**

Implementation of these principles has resulted in the successful reclamation of thousands of acres of pre-law soils throughout the midwest and southeastern United States during the 1950's and 1970's. Rejection of past practices and these proven reclamation principles only to start over again ignores the lessons learned from successful field trials that have withstood the test of time. These old practices may only need modification or improvement for current implementation. These old principles of acid soil reclamation may never be considered trendy or sophisticated, but they bear consideration because they are simple and have been successful.

ACID SPOILS RECLAMATION

The principles of acid soil reclamation listed above have been the basis of reclamation practices at the Peabody Will Scarlet Mine pre-law "Old Works" area in Williamson County, IL. Often referred to as the "nation's worst" example of acid soils and water associated with pre-law mining, the "Old Works" area encompasses approximately 2,400 acres of acid spoils, gob and slurry, acid impoundments, and acid mine drainage. Formerly mined by Stonefort Mining Company, Peabody Coal Company assumed reclamation responsibility for the "Old Works" area when the Will Scarlet Mine was purchased in 1967.

Pre-law mining during the early 1950's and continuing into the early 1960's affected more than 2,000 acres overlying the shallow Davis and Dekoven coal seams. Extremely acid sandstones and shale characterized the roof and partings associated with the two coal seams (fig. 1). Oxidation of exposed pyritic materials in spoils and refuse areas contributed to acid runoff (table 1) exceeding 700 million gal/year.

DEKOVEN-DAVIS OVERBURDEN: STONEFORT MINING

DEPTH (FEET)	ROCK TYPE	% SULFUR	PH (1:1)	NEUTRALIZATION POTENTIAL (TONS $CaCO_3$/1,000 TONS)	COLUMNAR SECTION
0-8	LOESS	0.030	5.0	1.11	L
8-25	OW-TILL	0.005	7.0	2.55	OW-T
25-31	OW-TILL	0.060	7.7	336.00	OW-T
31-32	LIMESTONE	0.565	7.8	482.77	LS
32-54	MUDSTONE AND SANDSTONE	0.170	7.6	12.05	MS SS MS SS
54-62	MUDSTONE	0.120	7.9	40.75	MS
	SANDSTONE	0.105	7.3	38.22	SS
62-66	SANDSTONE	2.850	3.2	-88.29	SS
66-72	SANDSTONE	1.090	5.1	-10.73	
72-74	COAL-DEKOVEN				COAL
74-76	CARBOLITH	12.050	2.4	-373.04	CARB
76-77	COAL-DEKOVEN				COAL
80-83	COAL-DAVIS				COAL

OW- GLACIAL OUTWASH

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Figure 1. Palzo generalized overburden sequence (Smith et al. 1976).

Table 1.—Peabody Will Scarlet Old Works plant influent water quality.[1]

Parameter	Range
pH	2.4 - 3.1
Acidity[2], boiling point to pH 8.3	1,700 - 9,200
Acidity[2], cold with H_2O_2 to pH 7.3	1,500 - 8,500
Alkalinity[2], to pH 4.5	0 - 93
Specific conductivity[3]	2,800 - 7,900
Iron, total (ppm)	145 - 1,130
Iron, ferrous (ppm)	0 - 65
Iron, ferric (ppm)	145 - 1,070
Sulfate (ppm)	2,200 - 6,600

[1]From: McDonald and Grandt 1981.
[2]ppm as $CaCO_3$.
[3]µmhos/cm at 25°C.

To abate acid discharges, a mine drainage water treatment plant was designed and constructed in 1970. Capable of treating 3.5 million gal of acid water with an average acidity of 4,500 ppm each day, plant operation costs have averaged $400,000 annually from 1971 through 1984. However, without concurrent reclamation within the acid watershed, it was recognized that the plant would be needed to perpetually treat the symptoms of acid spoils runoff.

In the late 1970's under the supervision of Jim Sandusky, a reclamation program was initiated to address the acid sources rather than perpetually treat the symptoms. Previous research at Will Scarlet had identified the beneficial aspects of natural leaching in reducing acidity and salinity of weathered spoilbanks (McGrath 1972). Therefore, under this program, acid spoils were selectively graded to cover acute acid shale profiles and ensure minimal disturbance to weathered and leached materials while preserving existing vegetative cover (Nawrot et al. 1982a).

Selective grading, minimal grading, neutralization amendment, and vegetation enhancement and preservation are the major components of the Peabody "Old Works" acid spoils reclamation program. This reclamation approach emphasizes amelioration of limiting chemical factors and working with and enhancing the natural succession of vegetation on pre-law spoil areas (Lindsay and Nawrot 1981). Pre-law problem spoil areas can represent varying degrees of acidity/toxicity problems and often support a wide range of vegetative successional stages (table 2). Consequently, pre-reclamation site characterization is necessary to identify and map distinct reclamation units (table 3).

Designation of reclamation units can minimize unnecessary grading. Adhering to the first principle of acid soils reclamation - "It it's not broke, don't fix it" only those areas most in need of reclamation are treated. While Class I and II spoil areas may require aggressive reclamation efforts (e.g., grading, selective soil covering, and subsurface neutralization amendment), extensively aged and leached Class III and IV spoils may only require supplemental surface neutralization amendment and vegetation enhancement. Simplifying reclamation by grouping spoil classes I-IV may appear to be more efficient; however, the exposure of previously unoxidized acid spoil during unnecessary grading of weathered spoils (e.g., Class III and IV) can produce more extensive areas of acute acid production than existed before reclamation. Covering acid spoils or reclaiming acid impoundments with fill material from vegetated pre-law spoils does not necessarily eliminate an acid problem if soil profiles within the borrow area contain previously unexposed acid shale. Unless soil/spoil profiles of potential borrow areas are documented with soil core data or there is qualified field supervision during construction, identification of borrow areas should not be based simply on the criteria that they are nearby and well vegetated.

These back-to-basics lessons of acid spoils reclamation have been demonstrated at the Peabody "Old Works" area since the mid-1960's. Current and future reclamation continues to rely on these basic principles. Spoilbank reclamation has emphasized limestone amendment (20-40 tons/acre) of previously graded spoils (e.g., Class IIIV), followed by cover crop establishment and/or domestic sewage sludge application for organic matter enhancement. Vegetative cover in amended spoils areas has included permanent seeding of warm season grasses (switchgrass (Panicum virgatum)) and supplemental tree planting. While supplemental tree planting has been desirable for enhancement of woody cover establishment, natural colouization by species in undisturbed spoils has successfully "reclaimed" adjacent areas.

Final reclamation of remaining "Old Works" spoil areas will occur during the next two years as more than 200 acres of marginal (Class I-III) spoil areas receive surface (0-9 inches) and subsurface (deep ripping @ 20-24 inches) limestone amendment. Amendment rates (≥50 tons $CaCO_3$ eq/1,000 tons) will exceed traditional limestone requirements (i.e., immediate + reserve + potential acidity) to enhance alkaline infiltration in subsurface spoil profiles. Dry sewage sludge will also be

Table 2.--Spoilbank classification for surface mine problem sites.[1]

	Spoil Class I	II	III	IV	V
VEGETATION					
Ground Cover %	0-5	10-20	20-30	30-40	40+
Successional Trend	mostly barren, advancement unlikely	scattered "islands" of herbaceous and woody cover, slow advancement	poor cover, but vegetation colonization expanding from "islands"	moderate cover with rapid colonization of bare areas	generally well developed herbaceous and woody cover
Years to Recover (natural colonization)	70+	50-70	10-20	5-10	0-5
SOIL LIMITATIONS					
pH	<3.5	3.5-4.0	4.0-5.0	5.0-6.0	≥6.0
Phytotoxicity	extensive potential acidity	high reserve acidity, extensive areas of phytotoxicity	moderately weathered, many "hotspots" remain	well weathered, only localized "hotspots" remain	accelerated organic matter accumulation and soils development
Nutrient Status	unavailable and deficient N, P, K, little or no organic matter	unavailable and deficient N, P, K contributing to poor growth and survival	low-medium nutrient availability, localized deficiencies common	localized deficiency	adequate macronutrients for sustained vegetative growth
RECLAMATION ALTERNATIVES					
Site Preparation	grading may be utilized with caution, soil substitutes may be necessary	grading may expose previously unweathered acid soils, amendments may be sufficient	grading discouraged, destruction of vegetation and exposure of acid subsoil likely, spot amendments as needed	do not grade	do not grade
Amendments	Limestone=50+ tons/ac NPK=80-100 lb/ac	Limestone=30-50 tons/ac NPK=50-80 lb/ac	Limestone=20-30 tons/ac spot application of NPK 20-50 lb/ac	limited amendments needed for enhancement and "spot" treatment	no amendments necessary unless for enhancement of existing cover

[1]Modified from Nawrot and Kolar 1982.

Table 3.— Spoil classification and associated pre-reclamation chemical characteristics[1] of the Stonefort Mining Company Pit 6 (Palzo Tract) pre-law graded spoil area[2] in Williamson County, IL. Samples collected March 1982.

Variable	Spoil Class I	II	III	III/IV	IV	V
	n=31	n=20	n=6	n=9	n=8	n=6
Potential Acidity (meq H^+/100g)	16 (3-50)[3]	14 (2-78)	9 (5-14)	8 (3-13)	9 (4-15)	8 (5-11)
Soil pH	2.7 (2.3-3.1)	2.8 (2.2-4.1)	3.6 (3.0-4.3)	4.1 (3.3-4.7)	4.1 (3.5-5.0)	4.9 (3.8-6.0)
Buffer pH	6.3 (6.0-6.6)	6.3 (5.8-6.7)	8.3 (6.4-6.5)	6.5 (6.4-6.8)	6.5 (6.3-6.7)	6.6 (6.4-6.7)
Conductivity (mmhos/cm)	2.2 (0.4-7.0)	2.2 (0.4-7.0)	0.7[4] (0.3-1.6)	0.5 (0.3-0.9)	0.5 (0.3-1.3)	0.3 (0.3-0.4)
Aluminum (ppm)	192 (79-393)	183 (58-291)	200 (91-387)	217 (72-391)	171 (50-407)	127 (2-313)
	n=10	n=8	n=4	n=4	u=5	n=1
Phosphorus (ppm)						
P_1 (weak Bray)	24 (12-44)	23 (14-36)	5 (3-8)	51 (7-97)	6 (4-10)	9
P_2 ($NaHCO_3$-P)	45 (19-72)	50 (29-101)	10 (5-14)	73 (13-144)	18 (14-23)	15
Potassium (ppm)	28 (11-58)	37 (16-108)	32 (18-52)	53 (26-64)	57 (41-79)	83
Magnesium (ppm)	49 (15-140)	59 (35-95)	58 (20-80)	81 (20-110)	109 (25-310)	170
Calcium (ppm)	540 (100-1,500)	568 (200-1,000)	300 (200-500)	453 (200-750)	510 (200-1,000)	600
Sodium (ppm)	29 (23-34)	25 (20-28)	26 (25-28)	29 (27-30)	28 (23-28)	30
Hydrogen (meq H^+/100g)	8 (8-12)	8 (5-12)	5.9 (4.6-7.0)	5.2 (3.7-6.6)	5.4 (4.0-7.2)	2.1
Cation Exchange Capacity (meq/100g)	11.0 (6.8-20.9)	11.4 (6.7-16.6)	8.1 (7.0-8.7)	8.4 (5.4-11.4)	9.1 (5.4-13.4)	6.9
Percent Base Saturation						
Potassium (%)	0.7 (0.3-1.9)	0.9 (0.3-2.5)	1.1 (0.6-1.6)	1.6 (1.2-2.3)	1.6 (1.3-1.9)	3.1
Magnesium (%)	3 (1.0-6.0)	4.6 (2.5-7.5)	6.1 (2.0-9.5)	7.8 (3.1-12.4)	8.5 (3.9-19.3)	10.5
Calcium (%)	21.1 (7.4-46.2)	24.8 (9.3-40.2)	18.6 (11.5-30.1)	26.6 (18.5-33.8)	26.5 (15.5-74.2)	43.5
Hydrogen (%)	73.6 (47.9-88.2)	66.4 (53.6-84.1)	72.7 (80.2-84.3)	62.1 (50.0-74.1)	52.0 (4.1-74.2)	30.4
Sodium (%)	1.3 (0.8-9.1)	1.0 (0.5-1.5)	1.4 (1.3-1.6)	1.8 (1.0-2.3)	1.3 (0.9-2.0)	1.9

[1]From Nawrot 1983.
[2]Mined early 1960's, graded 1971-1979.
[3]Mean (min.-max.)
[4]n=5.

applied to neutralized sandstone/shale spoils to increase soil moisture and organic matter. Limestone amendments and sewage sludge are being provided through an Illinois Abandoned Mined Lands Reclamation grant.

Productive forests or pasturelands in the "Old Works" area were never considered realistic reclamation goals. However, alkaline enhancement and vegetative stabilization of ungraded and graded spoilbanks, and the generation of alkaline rather than acid runoff now represent reclamation results that were considered only remotely possible more than 20 years ago.

REFUSE RECLAMATION

Current state regulations require a 4-ft soil cover for reclamation of recently inactivated coal processing wastes (gob and slurry). However, covering may not always be the most cost-effective solution for post-law and/or pre-law refuse. Although non-toxic cover materials provide rooting media for permanent vegetation, acid-base imbalance of the refuse materials and contamination of cover materials by upward acid diffusion may occur (Sukthumrong 1975). Consequently, prior to proceeding with "cosmetic" (i.e., soil cover) reclamation, consideration should be given to implementing a "chemical" reclamation approach that addresses restoration of a favorable acid-base equilibrium. "Treat and/or cover" alternatives including neutralization amendments can minimize or eliminate acidification of soil cover as well as enhance alkalinity of the refuse acid-base system in the upper zone (0-30 inches) of active oxidation (Warburton et al. 1987).

The feasibility of reclaiming pre-law refuse without soil cover is dependent upon unique geochemical characteristics associated with variations in seams and regional geology, as well as physical factors resulting from aging and weathering (Nawrot et al. 1982b). Similar to the previous discussion of spoil aging (McGrath 1972), amelioration of acute toxic conditions resulting from oxidation and weathering is also beneficial to reclamation of pre-law acid refuse. Natural colonization of old refuse sites by native vegetation (D'Antuono 1979) has illustrated that with time mine wastes can be transformed into mine soils.

Treating and/or reclaiming mine wastes withont soil offers both environmental and obvious economic benefits. Obtaining adequate soil cover can be expensive as well as detrimental to adjacent borrow areas. For most pre-law sites, adequate borrow areas were not planned for, making soil covering both impractical and expensive. Although covering can initially hide acidgenerating sources, vegetation established on thin soil veneers is often prone to drought stress and eventual erosion. Inadequate binding of soil caps due to shallow rooting inhibited by acid refuse substrates promotes sloughing and erosion of sollcovered slopes. Acid sites reclaimed with thin veneers of soil cover are extremely vulnerable to intensive post-reclamation uses. Overgrazing, neglect, lack of erosion control measures (terraces, rockdrains, etc.), or inadequate maintenance can contribute to site deterioration of AML projects.

Directly establishing vegetation on acid refuse without soil cover may not be appropriate for all sites due to topographic or hydrologic constraints. However, when feasible, building and developing refuse as a soil through alkaline and organic matter enhancement (limestone amendment and cover crop/green manuring) represents a practical approach to obtaining long-term chemical and vegetative stability of the reclaimed area. Enhancing and developing the refuse as a soil rather than reclaiming a soil cover placed over the refuse ensures that root establishment and plant cover will eventually bind and build the soil properties of the refuse substrate.

Direct vegetation establishment is best suited to those sites which have undergone an initial period of pyrite oxidation and weathering. When refuse is first deposited, little or no oxidation has occurred; consequently, immediate acidity is negligible and most materials are near neutral. Although variability occurs due to geologic and climatic factors (primarily temperature and rainfall), weathering and oxidation of fresh refuse results (after 12-18 months) in an initial acute acidification phase that is characterized by extreme concentrations of acid generation byproducts. Time required for initial acidification is variable, but may be shorter if adjacent areas contribute both acid runoff and sulfur-oxidizing bacteria to stimulate and accelerate acidification. Delays in acidification can be expected in refuse materials containing naturally occurring calcitic components; however, acid generation generally overcomes the neutralization potential due to the limited solubility of calcium carbonate. Other factors, such as particle size of refuse components, as well as weathering rates of parent material will also influence the onset and intensity of initial acidification.

Potential acidity gradually decreases (e.g., >80% reduction after 15 years in coarse refuse and only 3 years in unsaturated slurry) as fine-grained pyrite is depleted in the oxidized zone. However, chronic acid generation results from oxidation of remaining less reactive pyrite as well as the exposure of unreacted pyrite through erosion. If not disturbed by erosion or grading, a chemically stable weathered surface zone (0-36 inches) will gradually develop. Oxidized surface zones are characterized by "treatable" levels of potential acidity (e.g., 10-45 tons $CaCO_3$ eq/1,000 tons), while the underlying unoxidized zone (>100-200 tons $CaCO_3$ eq/1,000 tons potential acidity) remains relatively unreactive if not disturbed. Consequently, direct vegetation establishment is best suited to those sites that have been "abandoned" or have remained inactive and undisturbed for 5 to 10 years. Obviously, it is important that AML projects eliminate or minimize grading of weathered zones to prevent reexposure of unoxidized pyritic materials.

Gob Pile - Alkaline Enhancement and Direct Vegetation Establishment

To evaluate direct vegetation establishment (with limestone) as a cost-effective alternative for pre-law disposal sites a reclamation demonstration was initiated in 1971 by the Illinois Department of Mines and Minerals (Medvick and Grandt 1976) in cooperation with Peabody Coal Company at the Will Scarlet Mine. Reclamation of a 50-acre coarse refuse pile at the Peabody Coal "Old Works" area has emphasized the general principle of refuse aging and weathering. More specifically, reclamation was based on the previously identified principles: **Acidity = Lack of Alkalinity, and Time + Limestone = Green.**

When inactivated in 1971, surface refuse was extremely acid (pH 2.3, pyritic sulfur 4.4%) requiring approximately 130 tons/acre agricultural limestone to balance potential acidity requirements. Directly vegetated limestone-amended treatment plots were established by the Illinois Department of Mines and Minerals (Medvick and Grandt 1976) in the spring of 1971 followed in 1973 by a 0.5-acre demonstration plot. Refuse collected in 1977 from the amended and adjacent unamended portions of the experimental plot indicated limestone was effective in neutralizing surface acidity up to 3½ years after initial treatment.

To reduce chronic acid runoff in the "Old-Works" watershed, direct liming and seeding of the remaining surface area of the 50-acre gob pile was evaluated. Samples collected in March 1984 (table 4). reflected the physical and chemical effects of more than 12 years of aging and weathering. Continued oxidation and leaching had reduced potential acidity from >200 tons $CaCO_3$ eq/1,000 tons to <8 tons $CaCO_3$ eq/1,000 tons in the weathered refuse surface. Incremental sampling at 6-inch intervals indicated the zone of weathering had extended to a depth of 18 to 24 inches. Beyond the depth (30-36 inches) of physical weathering from freezing and thawing, oxidation of pyrite had been minimal.

A direct vegetation establishment reclamation plan was initiated in fall 1984 that emphasized minimnm surface disturbance and maximum alkaline enhancement of the weathered surface zone. The "excess alkaline enhancement" plan included limestone amendment for immediate and reserve acidity and sufficient amendment for future oxidation as indicated by potential acidity values of previously unoxidized snbsurface refuse. Surface broadcast application as well as subsurface incorporation (24-30 inch deep furrows @ 3-5 inches wide and 8-10 ft apart) were designed to provide an extension of the amended (neutralized) zone through alkaline infiltration into the unweathered coarse refuse.

Surface agricultural limestone amendment (@ 35-40 tons/acre) began in September 1984. After incorporation (disced to 9 inches), furrows were prepared using a modified cable trencher. Agricultural limestone was then applied in the trenches (@ 40-50 tons $CaCO_3$ eq/1,000 tons). Agricultural limestone was surface applied again (@ 50 tons/acre) after deep ripping. After light discing (disced to 4-6 inches), treated areas were fertilized (18-46-0 at a rate of 400 lb/acre, 0-0-60 at a rate of 250 lb/acre) and seeded with winter rye (Secale cereale) (2 bu/acre).

In the spring of 1985, reclamation continued with the establishment of 31,000 black locust (Robinia pseudoacacia) seedlings followed by supplemental tree planting in spring 1986 of 250 pin oak (Quercus palustris), 250 sweet gum (Liquidambar styraciflua), 250 smooth sumac (Rhus glabra), and 500 silky dogwood (Cornus oblique). Although soil pit excavations in fall 1986 showed predominately lateral tree root development within the limestone-amended zone, successful establishment (>60% survival) and growth of black locust are providing nitrogen and organic matter enhancement. Supplemental seeding of sweet clover (Melilotus spp.) and red clover (Trifolium pratense) is providing additional cover in association with old field annuals (e.g., Setaria spp., Rumex spp., Plantago spp., and Potamogeton spp.) established by mulching with clover seed cleaning reject.

After limestone amendment, coarse refuse samples reflected the addition of excess alkalinity and buffering capacity (>120 tons $CaCO_3$ eq/1,000 tons) in the weathered zone and establishment of nonacid (pH 6.8) conditions (table 4). Decrease of acidity below the weathered zone was initially (December 1984) evident in deep samples ($\geq$12 inches); mean pH values 5.7 were recorded for materials that had previously been extremely acidic. Although subsequent sampling (1985, 1986, 1987) identified acidity (pH 3.2) below the zone of mechanical limestone incorporation, sufficient alkalinity remained in the weathered surface zone to maintain near neutral (pH 6.9) conditions (table 4). As current (fall 1987) neutralization potential values of amended surface refuse (158 tons $CaCO_3$ eq/1,000 tons) exceed the nearly depleted potential acidity (5.0 tons $CaCO_3$ eq/1,000 tons), persistence of non-acid conditions can be expected in the weathered surface zone. With the presence of excess neutralization potential in the amended zone, gradual dissolution of calcium carbonate and alkaline flushing to the underlying unweathered zone can further ameliorate acid conditions.

Final reclamation of the Will Scarlet gob pile will necessitate vegetation establishment on exposed slopes. Eroded steep slopes will require minimal grading prior to limestone treatment and/or soil covering. Where grading is necessary, a period of initial aging and weathering may be included to allow for chemical stabilization of freshly exposed pyritic materials.

Slurry Areas - Alkaline Capping and Organic Matter Enhancement

Similar to the 50-acre "Old Works" coarse refuse area, two large acid slurry impoundments (137 acres and 65 acres) represented extensive sources of continuous acid generation and

Table 4.—Physiochemical data for selected parameters of Peabody Will Scarlet IIA/IIB coarse refuse areas.

Sample	Paste pH	Conductivity (mmhos/cm)	Pyritic Sulfur (%)	Potential Acidity (T $CaCO_3$ eq/1,000 T)	Neutralization Potential (T $CaCO_3$ eq/1,000 T)	Phosphorus P_1 Weak Bray (ppm)	Phosphorus P_2 Strong Bray (ppm)	Extractable Metals K^1 (ppm)	Extractable Metals Al^2 (ppm)
BEFORE TREATMENT									
(April/May 1984)									
0-6 in. (n=16)	2.7	3.0	0.24	7.62	-2.20	2.6	5.5	20.5	65
>12 in. (n=14)	2.2	28.0	3.98	124.50	-8.97	11.1	29.3	59.2	496
AFTER TREATMENT									
(December 1984)									
0-6 in. (n=16)	6.8	2.7	0.28	8.59	122.22	1.3	5.4	116.4	<5
>12 in. (n=14)	5.7	3.2	2.09	65.25	13.76	1.7	5.9	63.9	47
(November 1985)									
0-6 in. (n=16)	6.9	2.4	0.15	4.75	135.07	2.2	15.7	71.5	<5
>12 in. (n=14)	3.2	5.0	1.99	62.26	3.09	1.4	2.6	22.9	91
(September 1986)									
0-6 in. (n=16)	6.9	2.7	0.21	6.56	170.20	0.3	6.1	156.3	<5
>12 in. (n=14)	3.6	6.1	1.87	57.39	2.21	2.9	4.2	51.8	<206
(October 1987)									
0-6 in. (n=14)	7.0	2.4	0.16	5.00	157.60	2.8	19.6	156.5	<5
>12 in. (n=14)	2.6	16.2	2.90	91.40	2.00	5.8	12.7	87.8	396

[1]Determined from NH_4OAc extract.
[2]Determined from saturated paste extract.

runoff. The 137-acre impoundment had undergone significant weathering of oxidized surface zones (table 5). However, chronic acid runoff would require perpetual treatment by the mine drainage neutralization plant. To further rednce acid water treatment loads and associated costs, a plan was developed to ntilize hydrated lime treatment plant sludge as an alkaline cap and oxygen infiltration barrier for exposed slurry areas. Residual nentralization potential (100-250 tons $CaCO_3$ eq/1,000 tons) and high alkalinity (pH 8.5) of the mine drainage treatment sludge were conducive to establishment of an alkaline substrate over acid slurry surfaces.

A 10-acre pilot study initiated in spring 1983 utilized lime sludge pumped from the treatment plant holding basin (Pit 10). After decanting and densification, the hydrated lime sludge substrate (2-10 inches deep) was fertilized, disced, and seeded with Japanese millet (Echinochloa crusgalli) to establish a moist soil cover crop.

Hydrated lime sludge capping was expanded to include slurry areas IA and IB (137 acres) and slurry areas IC3 and IC4 (65 acres). To facilitate capping, slurry embankments were raised (+5 ft) and the 137-acre impoundment was snbcompartmentalized by the construction of a 900-ftlong internal embankment. Emergency spillways and water level control valves were installed to allow sequential pumping and decanting. Hydrated lime sludge was pumped directly from the water treatmeut plant.

After 3 years of pumping, slurry substrates have been capped by varying thicknesses (3 ft to <1 inch) of lime slndge. Periodic flushing with alkaline treatment plant discharge water has ameliorated acute acid (pH 2.8, acidity >1,200 ppm $CaCO_3$) conditions within the slurry impoundments. Although the persistence of a favorable alkalinity-acidity balance has been limited in the past by acid runoff from unreclaimed watershed soils, current reclamation efforts are addressing neutralization deficiencies of immediately adjacent spoils. Concurrent with limestone amendment of adjacent spoils and restoration of alkalinity within the slurry impoundments, liquid sewage sludge is being applied at a rate of approximately 10 dry tons/acre to enhance vegetation establishment and promote microbial sulfate reduction (Tuttle et al. 1969).

Sewage amendment accelerates recovery of the hydrated lime sludge-capped slurry impoundments while providing a more desirable substrate for establishing moist soil and wetland plants. Existing stands of reedgrass (Phragmites australis) have now expanded aud are rapidly colonizing previously bare slurry areas. Plantings of other wetland species - threesquare (Scirpus americanus), hardstem bulrush (S. acutus), and river bulrush (S. fluviatilis) - have aiso responded favorably to amelioration of the previously acnte acid conditions. Additional plantings and broadcast seeding of the moist soil annuals chufa (Cyperus esculentus), wild millet (Echinochloa spp.), smartweed (Polygonum spp.), and dock (Rumex spp.) will continue during springsummer 1988 as seasonal drawdowns of sewage slndge-capped slurry impoundments are initiated. Drawdowns of wetland/slurry substrates promotes germination of broadcast-seeded species as well as enhances the natural colonization and expansion of existing vegetation. Secondary to reclamation benefits, the reclaimed slurry imponndments and associated wetlands in the "Old Works" area provide habitat (food, cover, nesting) for a resident flock of about 100 giant Canada geese (Branta canadensis maxima) and wintering habitat for 6,000-8,000 migrating geese (B. c. interior).

SUMMARY

Reclamation of a pre-law acid area as extensive as the "Old Works" project represents a tremendous challenge as well as an outstanding opportunity to apply the basic principles of reclamation. To address extreme acid soil and water conditions required an approach that worked with nature by minimizing fnrther disturbance in order to maximize reclamation results. While "further research" can be valuable if you can afford it, nothing has been lost by implementing techniques that have worked in the past. Acid soils require excess alkalinity; uo amount of excess limestone can be considered inappropriate in a 2,400-acre watershed that has generated nothing but acid runoff for more than 25 years. No amount of organic matter can be cousidered too much in acid shale and sandstone spoils and refnse that would require decades to recover naturally. Any reclamation approach that eliminated or even reduced acid generation at the source can be cousidered successful if it minimized perpetual treatment of the symptoms.

Ironically, the extreme conditions and extensive acreage of the "Old Works" area may prove to be the most important factors in its eventual reclamation. "Too large", "too acid", and "too expensive" were factors that deterred previous attempts to initiate a comprehensive reclamation program using a traditional approach (i.e., soil covering). Cousequently, a treatment plant was constructed and the source of the problem was ignored for many years. Fortunately, time and the beneficial aspects of aging and weathering contributed to amelioration of acute acid couditions through natural processes.

Reclamation problems remaining after 25 years still represent adverse conditious; however, these acid soils are now more readily "treatable" as the acid-base equilibrium has been transformed to a level where alkaline enhancement can restore and ultimately maintain favorable coufitions. Reclamation units which previously exhibited extensive acid conditions, now only coutaiu isolated zones of acid "hotspots". Continued reclamation efforts which eliminate these hotspots can complete the job that natural processes began more than 30 years ago when the pyritic overburden was first exposed. Volunteer establishment of vegetation on former refuse areas and restoration of alkalue waters in previously acid impouudments provide

Table 5.— Pre-reclamation chemical data (mean values) for surface (0-6 inch), intermediate (15-21 inch) and deep (30-36 inch) samples collected August 1983 from the Peabody Will Scarlet "Old-Works" slurry impoundment IA/IB.

Sample Location and Depth	1:1 pH	SMP pH	Conductivity (mmhos/cm)	Total Sulfur (%)	Pyritic Sulfur (%)	Potential Acidity (T $CaCO_3$ eq/1,000 T)	Immediate Acidity (T $CaCO_3$ eq/1,000 T)	Phosphate P_1 Weak Bray (ppm)	Phosphate P_2 Strong Bray (ppm)	Potassium (ppm)	Aluminum (ppm)	Iron (ppm)
IA												
6 in. (n=24)	2.2	3.6	21.8	3.08	0.76	23.60	-12.03	5.7	7.7	39.1	972	7,739
15-21 in. (n=8)	3.1	5.5	7.8	4.17	2.03	63.48	-2.33	8.2	15.1	16.0	274	1,404
30-36 in. (n=24)	4.9	6.4	5.9	5.37	3.00	93.73	+5.43	3.2	26.6	33.6	1,288	882
72 in. (n=5)	5.3	6.7	5.2	4.78	2.79	87.31	+9.11	2.2	17.5	30.3	242	171
Total	3.6	5.2	12.3	4.26	1.97	61.64	-2.15	4.8	16.9	33.2	945	3,590
IB												
6 in. (n=12)	2.2	2.7	23.0	2.45	0.21	6.62	-18.61	7.0	9.4	26.8	1,696	8,991
15-21 in. (n=5)	2.5	4.0	9.1	1.87	0.38	11.75	-8.74	10.2	14.9	13.1	518	1,958
30-36 in. (n=12)	3.0	4.6	7.7	2.94	1.30	40.55	-6.41	6.0	21.3	19.2	2,489	1,072
72 in. (n=2)	3.5	5.1	56	2.53	1.37	42.66	-3.41	1.5	29.1	49.6	179	120
Total	2.6	3.8	13.7	2.55	0.73	22.90	-11.32	6.8	16.2	23.1	1,715	4,219

encouragement and further incentive to complete a reclamation effort that was once considered unrealistic.

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