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CHARACTERIZATION OF RUNOFF WATER FROM COAL-WASTE DISPOSAL SITES IN SOUTHWESTERN ILLINOIS

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ABSTRACT

Coal wastes are the mineral matter rejected from coal during cleaning operations. The refuse consists mainly of shale, clay, pyrite, and waste coal. At many disposal sites in Illinois, considerable quantities of sediment, acidity, sulphate, and dissolved metals have been washed from these sites and have contributed to the degradation in quality of the receiving streams.

Hydrologic and water-quality data were gathered from three abandoned, unreclaimed, coal-waste disposal sites in southwestern Illinois. Two of the disposal sites were recontoured, limed, covered with 30 cm of glacial till and loess, fertilized, and seeded. Data collected one to two years after renovation of these sites indicated that: (1) runoff rates were significantly increased because the soil cover was less permeable than the coal waste; (2) peak runoff rates did not seem to be affected; and (3) acidity, sulphate, and metal concentrations in surface runoff waters were reduced by about 80-90% following reclamation. However, gradual increases in acidity, sulphate, and metal concentrations in runoff water at the Staunton site have occurred two years after reclamation and may continue to rise in the future. This indicates that the pyrite and iron sulphate salts contained in the coal wastes will make reclamation a gradual long-term process -- one that cannot be solved immediately by grading, liming, and covering with soil.

INTRODUCTION

Coal inevitably contains some amount of rock and mineral matter when it is mined. Sulphur in coal is undesirable because it is converted during combustion to sulphur dioxide, causing air pollution and acid deposition. Shale, clay, and other mineral matter are also undesirable in that they cause slagging and fouling problems in a boiler and contribute to excessive particulate matter in stack gases. Therefore, several types of density separation methods are commonly used to clean coal prior to its use. In 1974, 553 x 10^6 t of coal were mined in the U.S.; of that amount, approximately 241 x 10^6 t (44%) of coal were produced from mechanical cleaning, resulting in 89 x 10^6 t of coal-cleaning wastes [1]. In 1975, about 97 x 10^6 t of coal-cleaning waste were produced [2]. Present production rate of coal wastes is about 110 x 10^6 t per year and is likely to continue increasing in the future.

Two different types of wastes are created by most coal-cleaning methods. The coarse dense mineral wastes are deposited in large piles or valley fills. Once coal is removed, the remaining washwater contains fine coal and suspended mineral matter. This slurry material (fine waste) is pumped to impoundments where it is allowed to settle out of suspension. Prior to the 1970s, coal-waste disposal sites, in most cases, were neither properly designed nor reclaimed because state and federal requirements governing such activities were inadequate. Abandoned, unreclaimed coal wastes cover approximately 70,800 ha in the U.S. [3]. In Illinois alone, 2040 ha of waste piles and 1615 ha of slurry material lie unreclaimed [4].

The vast amounts of coal wastes that have amassed over the past century are causing considerable health, safety, environmental, and aesthetic problems, particularly in the northeastern and midwestern U.S. Mass movement of waste piles (slides) on occasion have killed people, destroyed homes, and devastated stream valleys. Erosion of wastes has caused sedimentation of streams, premature filling of reservoirs, and destruction of aquatic biota. Another persistent environmental problem is caused by the oxidation of pyrite. Coal refuse can contain up to 25% pyrite (by weight), which is oxidized and hydrolyzed when exposed to oxygen and moisture. When water comes in contact with the pyrite oxidation products (iron sulphate salts), the resulting runoff water or subsurface leachates usually have a very low pH (1.8-3.5) and very high concentrations of acidity, sulphate, and dissolved metals (alkali, alkaline earth, transition, and heavy). Drainage from coal-waste disposal sites has caused innumerable cases of serious water quality degradation in streams [5,6]. Trace metals in the runoff water are often at concentrations many orders of magnitude greater than limits recommended for aquatic biota or allowed for drinking water. Erosion caused by the runoff of surface water gradually removes weathered material from the surface of waste piles, thus exposing fresh pyrite and enabling continual long-term oxidation, acid production, and leaching problems to persist.

In 1976, this study of Illinois coal-waste disposal sites was initiated to (1) gain more information on the nature and magnitude of hydrologic and water-quality problems associated with old abandoned disposal sites and (2) determine to what extent the problems could be mitigated by grading and covering the coal wastes with a soil and vegetative cover. Based on information collected from unreclaimed and reclaimed disposal sites, an attempt was made to discern how grading, covering with soil, and vegetating coal-waste disposal areas affected (1) ratios of surface runoff to rainfall, (2) peak runoff rates, and (3) water quality of surface runoff.

The term "reclamation" in this paper is used broadly to mean the grading, liming, covering with soil, fertilizing, and seeding of a coal-refuse disposal site. Ideally, though, reclamation should also mean recuperation of a site over a long time period -- with vegetation reestablished and self-sustaining, with erosion controlled to an acceptable level, and with water quality near the ambient levels of adjacent undisturbed areas. Whether the current methods of restoration can result in wholly successful reclamation of a site is a topic of interest and great debate. Certainly, in cases of disposal areas that have steep slopes and contain pyrite, total reclamation of the site may be an indefinitely long process.

The main area of study was located in the upper Cahokia Creek watershed in southwestern Illinois. Rainfall, runoff, and water-quality data were collected from the unreclaimed Superior washery site and the reclaimed Staunton site [7,8]. In addition, numerous grab samples from the Staunton site in 1976, prior to reclamation, and from other disposal areas in the Cahokia Creek watershed were collected and analyzed for this study.

Data from earlier investigations [5,6,9-12] have been included in the present investigation to broaden its geographic coverage of water quality and provide additional hydrologic data for comparative purposes. These data were collected from the New Kathleen disposal site, before and after the site's reclamation, by Consolidation Coal Co. [9, 10] and Ohio State University [11]. Water-quality data of disposal site runoff have also been collected in the past by the Illinois Environmental Protection Agency in southwestern Illinois [12] and throughout the state by researchers from Southern Illinois University [6]. These data will be discussed and evaluated in this paper, along with data collected during our own investigation.

DESCRIPTION OF DISPOSAL SITES

The three primary sites in southwestern Illinois where data were collected are known as New Kathleen, Staunton and Superior. A former mine at the New Kathleen site was an underground operation, running from 1943 to 1955. Coal was mined from the Herrin No. 6 seam 34 m deep. The original waste pile covered an area of 16.2 ha, stood 19.8 m at its highest point, and contained about 1.5×10^6 m^3 of refuse (Fig. 1-a). Slopes of the pile edge ranged between 34° and 45° and were deeply gullied in most places. Surface drainage from the pile was generally west toward a local creek, which is dry during much of the summer. An additional 20.2 ha were occupied by a slurry disposal area.

In the summer of 1970, New Kathleen's waste pile was partially relocated and graded so that all slopes were 18° or less, agricultural limestone was added to the surface at a rate of 34 t/ha, and the refuse was then covered with 30 cm of natural soil material (Fig. 1-b). In drainage areas 2 and 3, additional soil cover was added -- a total cover of 60 and 90 cm, respectively. Fertilizer, seed, additional limestone (13 t/ha), and mulch were applied to the site in the fall of 1970 [10].

An abandoned mine located near Staunton, Ill., was operated from 1904 to about 1924. Herrin No. 6 coal was mined underground, 85 m below the surface, and cleaned on site. The steep-sided waste pile was 1.4 ha in area, about 25 m tall at its highest point, deeply eroded, and barren of vegetation. Beneath the oxidized surface zone, total sulphur content of the waste material ranged from 5.5 to 8.5% (by weight), with pyritic sulphur ranging from 4 to 6%. Slurry material, deposited in a former sedimentation pond located north of the pile, occupied an area of about 4.5 ha. It, too, was deeply eroded and nearly barren of vegetation.

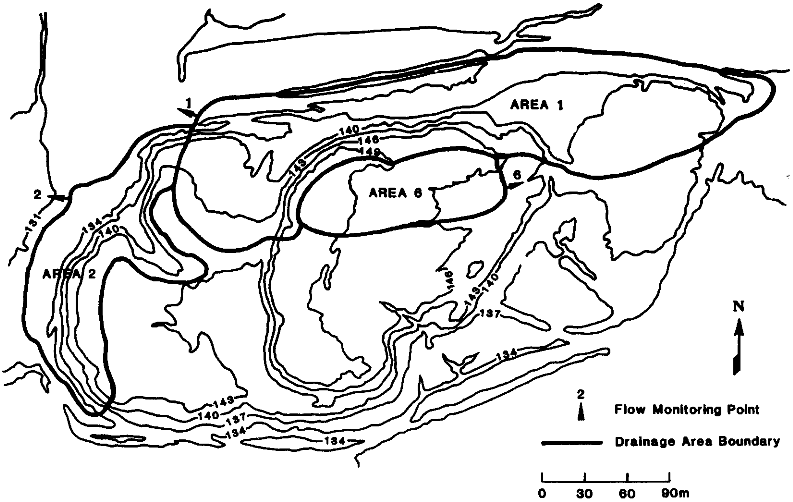

Fig. 1-a Drainage Areas and Flow Monitoring Points at New Kathleen Site, Prior to Its Reclamation

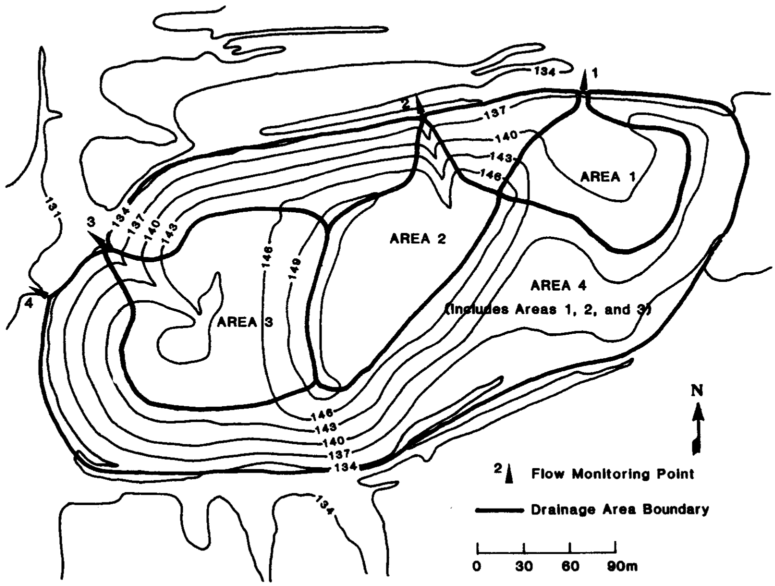

Fig. 1-b Drainage Areas and Flow Monitoring Points at New Kathleen Site, Following Its Reclamation

In early 1977, the state of Illinois provided funds to grade the Staunton disposal areas, neutralize the surface of the refuse with 168 t/ha ($CaCO_3$ equivalent) of agricultural limestone and hydrated lime, and cover the areas with 30 cm of glacial till and loess. The soil cover was fertilized and seeded in April 1977 [13]. During regrading operations, the waste pile height was reduced to about 5 m, and slopes were reduced to less than 12°. Total area of the pile was increased from 1.4 ha to 3.5 ha (Fig. 2). In the northern area, the slurry material was graded, limed, covered, and seeded. A retention pond was excavated in glacial till next to the slurry material for sediment control. Surface runoff from most of the reclaimed waste pile and all slurry materials flows into the pond and then discharges into a stream flowing northwest to Cahokia Creek (Fig. 2).

At a washery site operated by Superior Coal Co., located 15.4 km north of Staunton, coal was cleaned from four nearby underground mines. When these mining and washing operations ceased in 1954, about 688,000 m^3 of wastes had been produced, covering 23.5 ha. The two main piles in the center of the site stand 13.7 m high and cover an area of 1.5 ha at their base. The rest of the disposal site contains flat, graded wastes overlying slurry material (Fig. 3). The southern two-thirds of the site drains into a channel flowing southeast toward Spring Creek. The northern portion of the disposal site drains into a channel flowing northeast, also into Spring Creek (Fig. 3). The site is presently unreclaimed, devoid of vegetation, and discharging large quantities of sediment, acidity, sulphate, and dissolved metals into the watershed.

HYDROLOGY

Rainfall and runoff data from the three disposal sites were analyzed for the following time periods: the reclaimed Staunton site (July-Dec. 1977), the unreclaimed Superior washery site (1978), and the New Kathleen disposal site (pre-reclamation, 1970; post-reclamation, 1972). H-type flumes and water-level recorders measured runoff from three sub-drainage areas on the pre-reclamation pile at New Kathleen (Fig. 1-a). The same type of equipment was used on three sub-drainage areas of the post-reclamation pile (Fig. 1-b) and also at a point representing discharge from the entire pile (Area 4). Precipitation was recorded on site during both phases.

Two 90° V-notch weirs and water-level recorders continuously measured discharge from both the southern and northern drainage areas at the Staunton site (Fig. 2). The southern drainage area included the reclaimed waste pile, small portions of adjacent farm fields, and road ditches. Drainage through the northern weir included runoff from the southern drainage area, the entire slurry disposal area, and some additional farm lands (Fig. 2). Precipitation was recorded on site using a tipping-bucket rain gauge. An H-type flume with water-level recorder and tipping-bucket gauge measured runoff and rainfall at the Superior site (Fig. 3).

Hydrographs from Staunton and Superior sites were digitized, converted to flow rates using the appropriate weir or flume equation, and integrated using an IBM fourth-order Runge-Kutta variable step routine [14] to determine total flow volumes for each storm. The runoff coefficient, C, was calculated for individual storm events at all three sites by

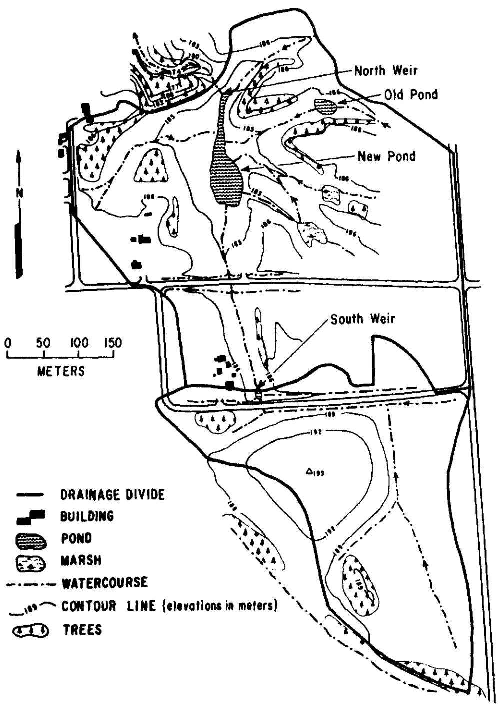

Fig. 2 Drainage Areas and Monitoring Points at Staunton Site, Following Its Reclamation

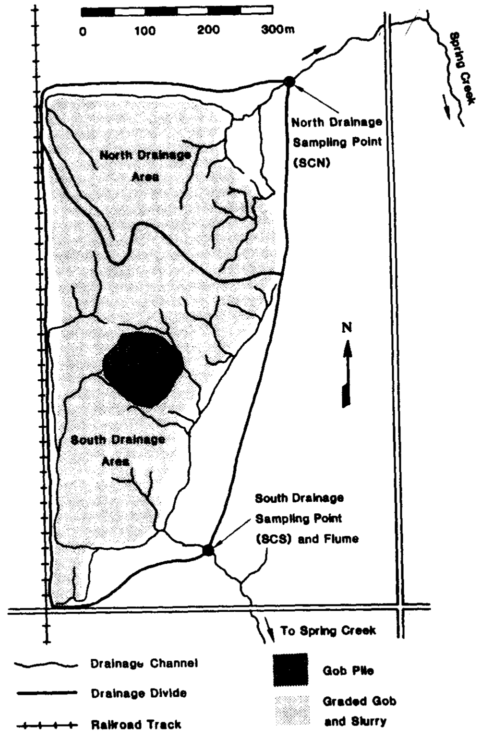

Fig. 3 Drainage Areas and Monitoring Points at the Unreclaimed Superior Site

dividing total storm runoff volume by total storm rainfall. An adjusted peak flow rate, M, was calculated by dividing each storm peak flow rate (m^3/s) by storm rainfall amount (cm) and drainage area (m^2), in order to facilitate comparison between sites and to eliminate the variable of rainfall amount. Values for these parameters are shown in Table 1.

The topography of the drainage areas appeared to have some effect on the runoff coefficient, C. When comparing the unreclaimed sites, the average runoff coefficient for Superior's southern drainage area (0.09) was lower than for Areas 1, 2, and 6 at the New Kathleen site (0.17, 0.23, and 0.45, respectively). The waste pile at Superior had slopes up to 45°, but it occupied only 10% of the southern drainage area; the rest of the area was relatively flat. Areas 1, 2, and 6 at New Kathleen, however, were located entirely on the steep-sloped pile (Fig. 1-a). Therefore, the steep slopes at the unreclaimed New Kathleen site could account for a higher runoff ratio than the one found at Superior.

Comparisons of runoff coefficients for the reclaimed sites (Table 1) show that the average values for New Kathleen sub-basins were generally greater than those for Staunton. The average value for Area 4 of New Kathleen (representing runoff from the entire pile) was 0.36; the average runoff coefficient for the Staunton reclaimed pile (southern drainage) was 0.31. For the reclaimed areas, the steeper slopes at the New Kathleen site appeared to account for greater runoff ratios. In addition, the waste pile at Staunton occupied only about 20% of the southern drainage area.

Comparison of average runoff coefficients between reclaimed and unreclaimed sites shows that the reclaimed sites generally had higher runoff ratios than the unreclaimed sites. The average runoff coefficient for New Kathleen (calculated on data from all sub-basins) increased from 0.28 for the pre-reclamation phase to 0.40 for the post-reclamation phase, an increase of 43%. Comparing the topographically similar Superior and Staunton sites, the Superior (unreclaimed) coefficient was 0.09 and the Staunton post-reclamation coefficient was 0.30. The increased runoff coefficients observed at the two reclaimed sites are due to the placement of soil cover (glacial till and loess), which is less permeable than the coal wastes. These increases occurred despite reduction in slopes and establishment of vegetation, actions that should have the effect of decreasing runoff. The overall increase in surface water runoff due to reclamation activities is balanced by decreased water seepage into the buried coal wastes.

Average adjusted peak flow rates for one unreclaimed site (Superior) and two reclaimed ones (New Kathleen, Staunton) were calculated (Table 1) and ranged from 9×10^{-8} to 4×10^{-7} m^3/s per cm of rain per m^2 of drainage area. Based on the limited amount of data, no significant difference could be detected between the three sites.

WATER QUALITY

Important goals of any effort to reclaim coal-waste piles are reductions in the acidity, toxic metals, and total solute concentrations contained in surface water runoff. When waste materials are exposed to the atmosphere, sulphide minerals such as pyrite and sphalerite become oxidized and form acid metal sulphate salts. Water from rainfall and

Table 1 Hydrologic Characteristics of Coal-Refuse Disposal Sites

Site	Drainage Basin	Drainage Area (ha)	Number of Storms	Range of Rainfall (cm)	Runoff Coefficient, C (dimensionless)			Adjusted Peak Runoff Rate, M[a]		
					Mean	Std. Dev.	Range	Mean	Std. Dev.	Range
Staunton (reclaimed)	Entire	24.47	17	0.28–9.75	0.29	0.28	0.01–0.86	90	107	1–357
Staunton (reclaimed)	Southern	7.76	19	0.25–5.44	0.31	0.25	0.03–0.78	201	144	16–776
New Kathleen (unreclaimed)	Area #1	4.98	5	0.51–1.88	0.17	0.09	0.05–0.29	--	--	--
	Area #2	1.60	22	0.38–3.51	0.23	0.15	0.02–0.57	--	--	--
	Area #6	1.10	28	0.25–3.51	0.45	0.28	0.08–0.96	--	--	--
New Kathleen (reclaimed)	Area #1	1.29	5	0.38–5.97	0.28	0.38	0.00–0.72	--	--	--
	Area #2	1.70	6	0.20–5.97	0.50	0.38	0.02–0.94	--	--	--
	Area #3	2.24	8	0.20–5.97	0.44	0.37	0.02–0.88	--	--	--
	Area #4	14.10	8	0.20–5.97	0.36	0.27	0.00–0.65	278	156	26–520
Superior (unreclaimed)	Southern	15.71	7	0.30–3.15	0.09	0.06	0.01–0.17	403	343	77–855

[a] $10^{-9}\left(\dfrac{\text{peak flow rate, m}^3/\text{s}}{\text{rainfall, cm} \cdot \text{drainage area, m}^2}\right)$

snowmelt can dissolve these oxidation products and transport them either through the waste material (emerging as seeps at the base of the pile) or as overland flow. Further leaching and dissolution of alkali, alkaline earth, transition, and heavy metals from the shales and clays in the coal wastes subsequently occurs. The resulting highly acidic water can contain potentially toxic concentrations of iron, manganese, and trace metals, and it may therefore cause severe environmental degradation to surrounding vegetation and streams.

The quality of runoff water from unreclaimed disposal sites has been extensively documented [5,6,8,12,15]. Table 2 summarizes data reported by Nawrot et al. [6] and Prodan et al. [8] for drainage from abandoned disposal sites in Illinois. In both cases, drainage from these sites is characterized by low pH, high acidity, and moderate to extremely high concentrations of iron and sulphate. Where data are available, concentrations of other metals such as manganese and aluminum are also high (up to 145 and 3100 mg/L, respectively). Although the quality of surface water runoff varies considerably from site to site, the data in Table 2 clearly indicate the potential adverse impact these runoff waters can have on the local environment.

Reclamation efforts to control acidic runoff from the New Kathleen and Staunton coal-refuse sites have focused on three areas of activity.

1. Chemical treatment of the waste material surface with neutralizing amendments.

2. Prevention or minimization of water contact with the waste material by decreasing infiltration (using a soil cover of relatively low permeability) and increasing transpiration during the summer by establishing vegetation.

3. Creation of an oxygen barrier at the surface of the waste pile, by establishing a soil and vegetative cover -- the soil acts as a physical barrier and root respiration consumes oxygen.

While the application of these reclamation principles has shown short-term effectiveness in controlling acidic runoff from research plots and under laboratory conditions, very few data are available to demonstrate long-term success under actual field conditions. Water-quality data from the two demonstration sites that were reclaimed (New Kathleen, Staunton) and the unreclaimed "control" site (Superior) were evaluated during this investigation to determine if significant long-term temporal trends had occurred as a result of reclamation efforts.

Water-quality data from the New Kathleen site have been previously published [9,10]. During a 15-month period preceding reclamation activities, water quality was sampled at the discharge measuring points described above. Samples were analyzed for pH, acidity, specific conductance, total and ferrous iron, and sulphate. Following regrading of the pile and application of an earth cover in 1970, sampling of runoff water was conducted for a three-month period in 1972 (no reliable data were collected in 1971). During this short post-reclamation period, samples were only analyzed for acidity.

Table 2 Water Quality of Runoff from Selected Illinois Coal-Refuse Areas

Location and Source of Data	No. of Samples		pH Value	Total Acidity, as $CaCO_3$ (mg/L)	SO_4 (mg/L)	Total Fe (mg/L)	Al (mg/L)	Mn (mg/L)
Statewide [6]	110	Median	3.0	415	1300	57	37	6.4
		Mean	3.5	3200	5200	510	240	21
		S.D.	1.54	6450	10780	1260	513	31.1
		Min.	1.6	4	31	0.36	0.1	0
		Max.	7.8	39300	89000	10000	3100	145
Cahokia Creek watershed [8,12]	25	Median	2.8	6400	4500	1025	--	--
		Mean	2.9	8962	5972	2220	--	--
		S.D.	0.29	7300	4514	3030	--	--
		Min.	2.4	640	1200	55	--	--
		Max.	3.6	30150	19375	13500	--	--
Staunton site, pre-reclamation (1976)	5	Median	2.85	3596	5914	1450	482	31
		Mean	3.37	3568	6328	1272	457	28
		S.D.	1.02	687	1710	429	105	5.2
		Min.	2.70	2425	3875	589	289	19.5
		Max.	5.40	4412	9058	1810	607	33
Staunton site, post-reclamation (1977-80)	27-30	Median	4.10	176	900	1.46	9.8	6.1
		Mean	4.54	361	957	9.2	33.9	7.2
		S.D.	1.59	484	564	14.4	38.9	4.6
		Min.	2.56	4	140	0	0	0.1
		Max.	7.95	1941	2150	52.8	135	20.3
Reduction from mean concentration before reclamation (%)			93[a]	90	85	99	93	74

[a]Percentage of reduction in hydrogen ion concentration.

During a six-month baseline study in 1976 at the Staunton site, grab samples of runoff leaving the site (North Weir, Fig. 2) were analyzed for pH, acidity, specific conductance, sulphate, and an array of metals and trace elements including aluminum, iron, manganese, and zinc. Sampling was also conducted during reconstruction activities at the site in early 1977, and the process continued for a 44-month period following reclamation. With few exceptions, the same parameters as listed above for pre-reclamation were also analyzed for each sample during the post-reclamation phase.

Finally, in conjunction with the groundwater-quality research being conducted at the Superior site [15], samples were obtained of surface water runoff at two locations (stations SCS and SCN, Fig. 3) on the site. These samples, collected over a 29-month period in 1978-80, were analyzed for the same parameters as the Staunton samples.

Because recontouring of the waste pile at the New Kathleen site resulted in vastly different individual sub-basins monitored for flow volume and water quality, direct comparison of specific pre- and post-reclamation portions of the pile could not be made. Therefore, the two largest areas monitored during both periods were chosen for comparison on the basis of most closely representing overall effluent from the pile (Flow Point 1, Fig. 1-a; Flow Point 4, Fig. 1-b). In addition, since only acidity of water samples was determined after reclamation at the New Kathleen site, this was the only parameter used for analysis of conditions at each site. Acidity levels generally reflect the degree and rate of formation of sulphide mineral oxidation products, so this was considered a valid indicator of reclamation success at each site.

Figs. 4-a, 4-b, and 4-c show concentrations of acidity plotted against time for the New Kathleen, Staunton, and Superior waste disposal sites, respectively. In Figs. 4-a and 4-b, acidity levels appear to show a dramatic decline in samples collected after reclamation activities compared to those collected before. This decline seems to indicate that placing an earth cover, adding neutralizing amendments, and establishing a vegetative cover can cause at least a short-term reduction in solution and transport of oxidation products in surface water runoff. Further evidence of this is shown in Table 2, which summarizes water quality at the Staunton site before and after reclamation. For each parameter listed, significant declines in average concentration have occurred following reclamation. As expected, no such declines in concentrations of acidity (Fig. 4-c) or other parameters were seen at the Superior site, where no reclamation activities took place. A correlation of acidity concentrations with flow rates, yielding total acid loads from the sites rather than absolute concentrations, would more accurately characterize oxidation and mass leaching rates of the piles before and after reclamation. Unfortunately, we lack the data necessary to perform this more detailed analysis.

Although the results of this simple analysis of the effects of reclamation on water quality are encouraging, several factors preclude a positive statement of long-term trends. First, post-reclamation data from the New Kathleen site are extremely limited (Fig. 4-a) both in quantity of samples obtained and in variety of constituents analyzed. Second, although a significant reduction in concentrations of acidity have occurred at both the New Kathleen and Staunton sites, these

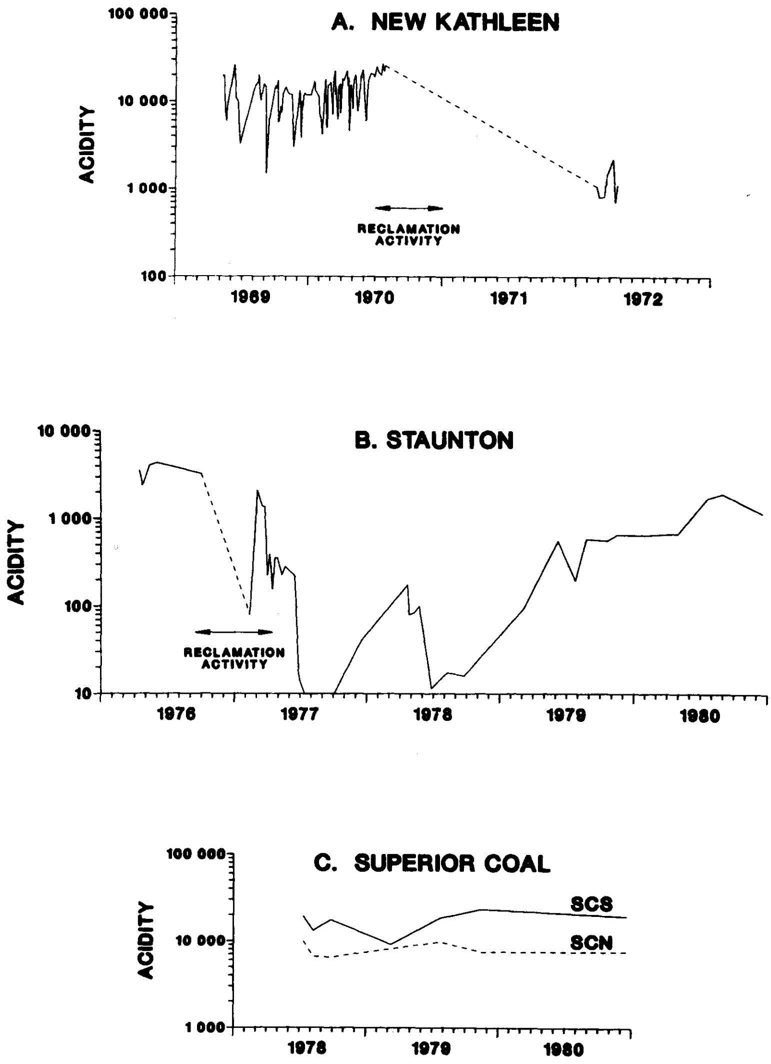

Fig. 4 Acidity, as $CaCO_3$ (mg/L), Vs. Time at Three Illinois Sites

post-reclamation concentrations still remain high relative to those in runoff from undisturbed land (usually alkaline). The data for Staunton (Fig. 4-b) are especially disturbing because it appears that runoff quality has deteriorated substantially during 1979-80. The deterioration is due, in part, to reexposure of waste materials in erosion gullies and the road ditch on the northern side of the recontoured pile.

CONCLUSIONS

Abandoned, unreclaimed coal-waste disposal sites in southwestern Illinois are usually devoid of vegetation and deeply eroded. They are also major contributors of sediment, acidity, sulphate, and dissolved metals to nearby streams. The success of current reclamation techniques used to control hydrologic and water-quality problems was evaluated using data from three disposal sites. The following conclusions have been drawn. (1) Covering coal refuse with silty clay glacial till and loess increased runoff rates. (2) The adjusted peak runoff rates, however, did not appear to be affected. (3) Water quality during one to two years following reclamation was greatly improved, with acidity levels reduced by about 90%. (4) Runoff water appears to be returning to highly acidic conditions after two to three years.

The decline in water quality shortly after reclamation is probably attributable to three causes. (1) The neutralization potential of lime and limestone applied to the surface of the coal wastes has been reduced. (2) Erosion gulleys have reexposed small areas of waste materials. (3) Iron sulphate salts were common throughout the piles prior to reclamation and continue to produce acidity, sulphate, and iron in leachates from the piles long after reclamation. Only long-term monitoring of these waste piles will determine whether pyrite oxidation and acid leachate production have been successfully reduced -- and true "reclamation" actually achieved.

ACKNOWLEDGMENTS

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