EVALUATION OF OVERBURDEN ANALYTICAL METHODS AS MEANS TO PREDICT POST-MINING COAL MINE DRAINAGE QUALITY[1]

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Abstract.--Prediction of the potential for acid drainage formation is required as part of the coal mine permitting process. Overburden analyses, by methods such as the acid-base account, are in common usage as part of this prediction despite the fact that a quantitative correlation between overburden properties and post-mining water quality had never been demonstrated adequately in the field. This study was designed to test the accuracy of predictions based solely on overburden analytical data. The study sites were selected to represent cases that have proven difficult to predict. Overburden samples were obtained from freshly exposed surfaces on highwalls or from cores preserved prior to mining. Post-mining drainage was analyzed at a reclaimed section of each site, paired to match the sampled overburden in terms of the presence and thickness of lithologic units. Overburden samples were analyzed by the acid-base account and a simulated weathering method. Overburden data were aggregated on thickness- and volume-weighted bases and water quality data were aggregated on a flow-weighted basis for each site. Drainage net alkalinity was correlated significantly ($p<0.05$) with the volume-weighted acid-base account parameters acid potential, neutralization potential, and net neutralization potential ($r=0.358$, 0.4197, 0.3799, respectively). However, when five sites having net neutralization potentials greater than 20 tons/1000 tons were excluded, these relationships became insignificant. Acid base account data showed boundaries useful in predicting the acid or alkaline character of post-mining drainage but no quantitative predictive equation could be developed. Simulated weathering test data correlated with actual sulfate concentrations in the post-mining seeps ($r=0.4089$, $p=0.046$), but the alkaline or acid nature of the seeps was not correlated with laboratory data ($r=0.088$, $p=0.364$).

INTRODUCTION

Overburden analysis came into widespread use with passage of the Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87). The law requires, as part of the permitting process, the identification of potentially acid-producing strata and determination of the probable hydrologic consequences of mining, including water resource degradation. Because little research had been conducted on water quality prediction, the regulatory authorities and industry initially had to adapt available methods to these purposes.

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The acid-base account method of overburden analysis was developed in the early 1970's for identification of strata that could be used as soil substitutes in revegetation of coal mines (Smith et al 1974). The method (described subsequently in this paper) is based on determining whether the capacity of a stratum to produce acid via pyrite oxidation is greater or less than the ability of the same stratum to neutralize strong acid. A neutralizer deficiency greater than 5 tons/1000 tons as calcium carbonate equivalent[3], a figure common for natural soils in West Virginia, was the recommended standard for identifying strata unsuited for supporting vegetation.

This method was adopted widely as the overburden analytical tool for identification of acid and toxic strata. The term "toxic" was meant to indicate toxic to plants by virtue of high acidity levels. While the purpose and application of the method was delineated clearly in the literature, its more recent use as an indicator of water quality is not clearly defined.

Based on the real or perceived failure of the acid-base account to identify acid-producing strata and predict whether or not post-mining discharges would comply with regulatory standards, interest in other overburden analysis methods has grown. The numerous alternative methods can be classified as static or kinetic; the former rely on bulk rock properties while the latter take into account the rates of relevant reactions. Simulated weathering tests are kinetic methods that aim to accelerate in the laboratory the reactions that take place in the field setting. Common static and kinetic tests have recently been reviewed (Ferguson and Erickson, 1987).

At the start of this study, none of these methods had been adequately evaluated by comparing the predicted water chemistry to actual drainage chemistry. That is, there was no procedure for interpreting the results to predict post-mining water quality or character with a known degree of accuracy. The purpose of this study was to define the predictive capability of overburden analytical methods by applying them to many mine sites. Post-mining water quality measurements were made at the discharge points from reclaimed mine sections. Pre-mining overburden samples were collected from preserved cores or from fresh channels cut in extant highwalls. These samples were analyzed using the acid-base account method and a simulated weathering test. The results of both overburden tests were then compared with the water quality results to determine if significant correlations exist.

METHODS

Technical Approach

Thirty-two sites were selected for the study, each comprised of a pre-mining section and a post-mining reclaimed section, so that pre- and post-mining data could be gathered simultaneously. The general concept was developed at the Bureau of Mines while the detailed approach was developed by Engineers International in response to our request for proposals. The contractor and its subcontractor, Sturm Environmental Services, selected all sites, conducted all sample collection and performed all water and rock analyses. Bureau personnel conducted all data analysis following completion of the contract.

Sites were selected to represent cases that are difficult to predict. Overburden columns completely dominated by either acidic or alkaline strata were eliminated from consideration. Sites that were backfilled or reclaimed using acid-mitigating methods, such as selective spoil placement or surface alkaline addition, were also excluded. To minimize effects of local geology, sites in Pennsylvania, West Virginia, Maryland, Illinois and Kentucky were included in the study. Sites in west-central and southwestern Pennsylvania comprised about half of the study sites, through a prevalence of suitable candidates rather than through design.

Water Quality

Sampling and Analysis

Post-mining water quality data were collected from reclaimed spoil sections at 32 mine sites paired with overburden sampling sites. Water sampling and flow measurement were conducted at all discharge points identified during the initial visit to each site. The discharges that comprised the majority of the flow, usually two or three at each site, were sampled subsequently at least nine times over about a year. Primary measurement and analysis methods for parameters used in this report are shown in Table 1.

Table 1.--Analytical methods for selected parameters (U.S. EPA 1983)

Parameter	Measurement Method
Water flow........	Bucket and stopwatch, L/min
pH................	Electrometric, standard units
Acidity...........	Titration (hot, peroxide) to pH 8.3, mg/L as $CaCO_3$
Alkalinity........	Titration (cold) to pH 4.5, mg/L as $CaCO_3$
Net Alkalinity....	Alkalinity minus Acidity, mg/L
Sulfate...........	Colorimetric methyl thymol blue, mg/L

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[3] The unit, tons/1000 tons, derives from agronomy where 1000 tons is the estimated weight of an acre-plow layer of soil. The unit is identical to parts per thousand. $CaCO_3$ equivalent indicates the mass of calcium carbonate needed to yield a specific magnitude of electrical charge ($CaCO_3$ = 50 g/mol of charge). The unit is used so that terms of opposite charge, such as acidity and alkalinity, are additive.

Data Aggregation

Water quality data for each site were aggregated to produce a single value for each parameter by calculating a flow-weighted average:

$$\text{flow-weighted } X = \frac{\sum_{1}^{n} (\text{concentration of } X)(\text{flow})}{\sum_{1}^{n} (\text{flow})} \qquad (1)$$

where n is the total number of samples at the site for which flow and concentration of X were measured and X is the chemical quantity net alkalinity, sulfate, or iron in mg/L.

Overburden

Sample Collection

Overburden samples were collected in two ways to represent pre-mining conditions. At nine sites, well-preserved and well-documented core samples taken prior to mining of the reclaimed section of the site were used for analysis. In all other cases, a highwall that could be determined to match the backfill, in terms of the presence, thickness, and appearance of each lithologic unit, was sampled for overburden analysis. Highwall samples were collected from a channel of freshly exposed surfaces, with lateral displacement at lithologic boundaries where needed to represent the stratum as records showed it had existed in the reclaimed section prior to mining. The entire length of each lithologic unit was sampled to account for intra-stratum differences in composition. An average of eight rock units (individual strata or adjacent strata of similar appearance) were collected from each site.

Acid-base Account

Acid-base account analyses were conducted according to procedures developed at West Virginia University (Smith et al 1974, Sobek et al 1978) with minor modifications. The portion of the procedure that produced data used in this paper is as follows. Samples were air-dried, mixed, crushed to pass a 60-mesh sieve, and stored in sealed containers until analyzed.

Acid potential (AP) is defined as the amount of acid that would be produced if all pyrite in the sample reacted according to the following stoichiometry:

$$FeS_2 + \frac{15}{4}O_2 + \frac{1}{2}H_2O = Fe(OH)_{3(s)} + 2SO_4^{2-} + 4H^+ \qquad (2)$$

One mole of pyrite, containing 64 g sulfur, produces 4 moles of H^+ acidity, equivalent to 200 g $CaCO_3$ acidity. Thus, the acid potential of pyritic sulfur is 3.125 g acidity (as $CaCO_3$) per g sulfur; 1 pct pyritic sulfur has the potential to produce 31.25 tons/1000 tons acidity. Total sulfur concentrations were measured with an automated Fisher sulfur analyzer, consisting of a furnace and SO_2 titrator, according to the instrument instructions. Sulfur speciation was analyzed for samples containing more than 0.5 pct sulfur by hot extraction with hydrochloric and nitric acid to remove sulfate and pyritic sulfur, respectively. Organic sulfur was defined as the sulfur fraction remaining after acid extraction. AP was calculated from both total sulfur and, when analyses were available, pyritic sulfur. Total sulfur is often used in mine permit applications to minimize analytical costs.

Neutralization potential (NP), defined as the ability of the stratum to neutralize strong acid, was determined by treating a 2 g sample with 20 to 80 mL of 0.1 M HCl, heating nearly to boiling, and swirling periodically until no gas evolution was observed. The samples were made up to 125 mL with distilled water, boiled for 1 min, and cooled to room temperature. The treated sample was then titrated with standard NaOH (0.1 or 0.5 M) to pH 7. NP was calculated as the amount of HCl consumed by the sample and converted to the units of tons $CaCO_3$/1000 tons material:

$$\text{NP, tons/1000 tons} = \frac{\text{g HCl consumed}}{\text{g sample}} \times \frac{50 \text{ g } CaCO_3}{36 \text{ g HCl}} \times 1000 \qquad (3)$$

Net neutralization potential (NETNP) was calculated for the stratum by subtracting AP from NP. A positive NETNP indicates an excess of neutralizers while a negative NETNP indicates a deficiency of neutralizers in the stratum.

Simulated Weathering

A simulated weathering procedure was applied to all samples from 18 of the 32 study sites. The subset of sites, necessary to save cost, was selected to cover the range of post-mining water quality observed at all sites and to include sites for which true water quality and acid-base account results conflicted.

Samples were crushed to pass a 2-mm sieve and 300 g portions were placed in a thin layer on the bottom of weathering chambers. The chambers were each rinsed with 300 mL of distilled water; the collected leachate was labelled "week 1" and analyzed. An inoculant of 10 mL of acid mine drainage was then added to each sample to establish a population of iron-oxidizing bacteria. For the next 5 to 8 weeks, leaching was performed on a 7-day cycle: dry air was passed over the sample for 3 days; humidified air was passed over the sample for 3 days, and leaching occurred on the last day, by the addition of 300 mL of distilled water for 1 hr followed by draining. Any fines washed out during draining were collected by centrifugation, resuspended in a small amount of water, and returned to the chamber. The leachate volume was measured and portions were analyzed for pH, acidity, alkalinity, iron, and sulfate (table 1).

Leachate composition from each sample was aggregated over the duration of the weathering test to calculate cumulative loads of pollutants. Cumulative load of net alkalinity (alkalinity minus acidity) was calculated according to:

$$\text{Cumulative net alkalinity, mg} = \sum_{2}^{n} \left[(\text{net alkalinity, mg/L})(\text{leachate volume, L})\right] \qquad (4)$$

where n is the total number of weeks of leaching. Cumulative sulfate load was calculated in the same manner.

The same simulated weathering procedure was also applied to composite samples from 5 of the study sites. Composite samples were made by mixing all the strata from a site in weight ratios equal to the thickness ratios of the strata in the overburden column. Equation (4) was again used to calculate cumulative product loads.

Data Aggregation

Overburden analytical data from both the acid-base account and single-stratum simulated weathering tests were aggregated in two ways to produce a single value to represent the entire overburden column at each mine. First, a thickness-weighted average was calculated as

thickness-weighted NETNP =

$$\frac{\sum_{1}^{n}[(\text{NETNP})(\text{thickness})]}{\sum_{1}^{n}(\text{thickness})} \tag{5}$$

where n is the total number of strata sampled at the site.

Second, a volume-weighted average, modelled after diPretorio's (1986), was calculated by substituting an estimated volume for thickness in the previous calculation. The volume of each unit was estimated by assuming that the mine cross-section was an isoceles right triangle, having two sides equal to the height of the overburden column. Using geometry, these assumptions yield the cross-sectional area of a stratum:

$$\text{Area} = 1/2\ (D_2^{\,2} - D_1^{\,2}) \tag{6}$$

where D_1 and D_2 are the depths of the top and bottom of the stratum, respectively.

Assuming constant length and constant density for all strata, the proportion of spoil produced from an individual overburden unit was calculated as:

$$\text{Fractional Volume} = \frac{D_2^{\,2} - D_1^{\,2}}{D_T^{\,2}} \tag{7}$$

where D_T is the total depth to coal.

Data Analysis

Data were entered and manipulated in Fortran-readable files on a VAX mainframe computer. Descriptive statistics, Pearson correlations and linear regression analyses were performed using SPSS-X software. The significance of correlations was judged at the 0.05 probability level.

RESULTS AND DISCUSSION

Water Quality

Descriptive statistics for selected water quality data are summarized at the individual sample and mine levels in Table 2. Samples collected from a single site often showed changes in water quality during the study period. Many sites had seeps of both acidic and alkaline drainage (fig. 1), and individual seeps occasionally changed character during the study period (fig. 2). Peak contaminant concentrations and loads occurred at different times of the year in different seeps (fig. 2). These observations are a reflection of the heterogeneity of both the spoil material and its local environment within the backfill (Ladwig and Campion; Lusardi and Erickson). They also illustrate the difficulty associated with using aggregated values to represent the entire mine site. However, as drainage from a site usually flowed into one water course, it seemed reasonable to attempt to weight the water quality parameters by flow to represent the site discharge.

Mean and median values of net alkalinity, iron, and sulfate were not in accordance with the stoichiometry shown in equation (2). Equation (2) produces 25 parts net acidity (or 25 parts net alkalinity) per 24 parts sulfate and no dissolved iron. Different stoichiometric equations describe pyrite oxidation at the low pH values that were observed at several sites:

$$FeS_2 + 14Fe^{3+} + \tfrac{1}{4}O_2 + 8H_2O = 15Fe^{2+} + 2SO_4^{\,2-} + 16H^+ \tag{8}$$

$$14Fe^{2+} + \tfrac{14}{4}O_2 + 14H^+ = 14Fe^{3+} + 7H_2O \tag{9}$$

$$FeS_2 + \tfrac{15}{4}O_2 + H_2O = Fe^{2+} + 2SO_4^{\,2-} + 2H^+ \tag{10}$$

Equations 10 and 2 yield the same ratio of acidity to sulfate (2 moles H^+ acidity and 2 moles latent H^+ acidity in the Fe^{2+} produced in equation 10 versus 4 moles H^+ acidity in equation 2). Equation 10 produces 25 parts net acidity and 7 parts iron per 24 parts sulfate.

Neutralization of pyrite oxidation products by carbonate minerals (e.g., $CaCO_3 + 2H^+ \longrightarrow Ca^{2+} + H_2O + CO_2(g)$) can decrease acidity relative to sulfate in the drainage. The accompanying rise in pH causes iron hydrolosis and precipitation. Only drainage from highly pyritic and neutralizer-free wastes, such as aged coal refuse, approaches the stoichiometry expected from equation (10).

Table 2.—Descriptive statistics for selected post-mining water quality variables.[1]

Parameter	Mean	Median	Range
All individual samples (n = 797)			
Net alkalinity, mg/L as $CaCO_3$.....	-109.	13.0	-2620. - 620.
Iron, mg/L.......................	14.1	2.68	0.00 - 99.0
Sulfate, mg/L....................	1090.	805.	23.0 - 4350.
Flow-weighted mine aggregate			
Net alkalinity, mg/L as $CaCO_3$.....	-130.	-30.6	-1630. - 536.
Iron, mg/L.......................	10.9	4.43	0.034 - 50.1
Sulfate, mg/L....................	1140.	826.	37.4 - 4020.

[1] Values rounded to 3 significant figures.

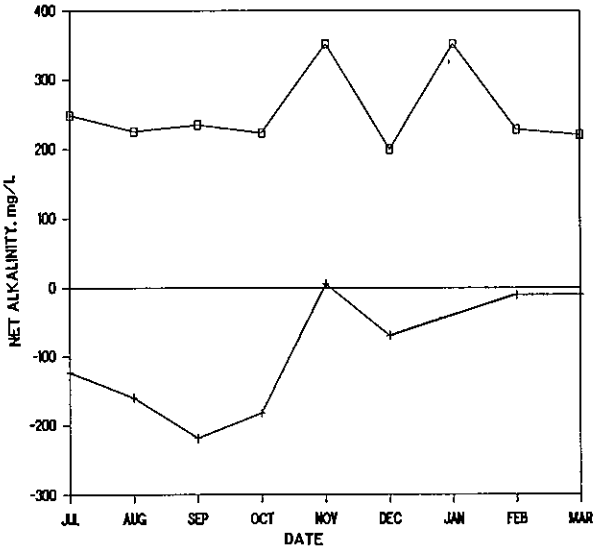

Figure 1.--The major seeps at site 21 discharged both acid and alkaline water.

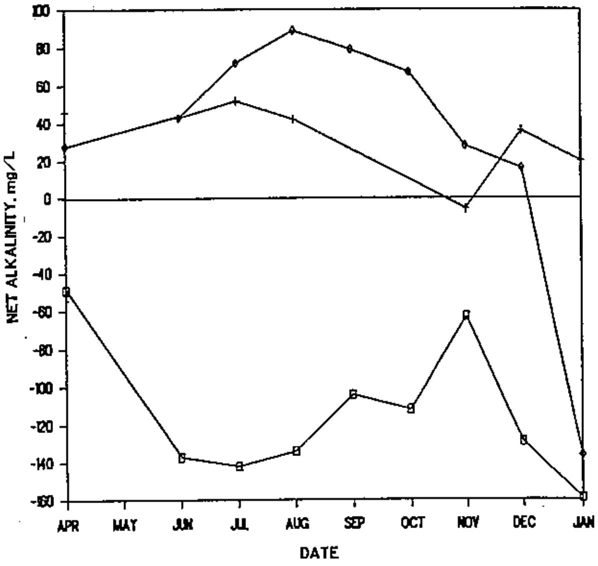

Figure 2.--Seep alkalinity at site 4 varied laterally and temporally.

Carbonate minerals in equilibrium with clean water at atmospheric pCO_2 are expected to yield less than 100 mg/L net alkalinity. Yet alkalinities measured at several sites in this study were higher, with a maximum of 620 mg/L (Table 2). Elevated pCO_2, possibly produced by acid dissolution of limestone, increases the solubility of carbonate minerals. Elevated pCO_2 levels have been measured in acidic coal mine spoil.

Aggregated at the mine level, net alkalinity ranged from -1630 to +536 mg/L, while mean sulfate concentrations ranged from 37.4 to 4020 mg/L (table 2). Seventeen of thirty-two sites produced acidic drainage. These values indicate that the site selection methods were adequate to identify mines that produced drainage of both acceptable and unacceptable quality.

Table 3.--Descriptive statistics for acid-base accounts.[1,2]

Parameter	Mean	Median	Range
All samples			
AP[2]............	21.6	5.84	0.031 - 258.
NP.............	37.6	8.41	0.22 - 937.
NETNP..........	15.8	1.77	-257. - 936.
Thickness-weighted mine aggregates			
AP.............	11.8	9.36	1.04 - 34.2
NP.............	38.1	13.4	3.43 - 272.
NETNP..........	26.2	5.81	-22.7 - 252.
Volume-weighted mine aggregates[3]			
AP.............	17.4	14.3	1.57 - 51.8
NP.............	39.1	15.3	3.30 - 197.
NETNP..........	21.6	4.01	-31.6 - 157.

[1] All values rounded to 3 significant figures or 2 decimal places.

[2] Total sulfur values that registered below the detection limit were recorded as 0.001 pct, giving rise to a single-stratum AP value of 0.031.

[3] Site 13 was omitted since insufficient data were available to estimate volumes.

Table 4.--Correlation between flow-weighted water quality parameters and overburden variables derived from acid-base account data.

Overburden variables, tons/1000 tons	Water Variables Correlation coefficients (probability) Flow-weighted net alkalinity mg/L as $CaCO_3$	Flow-weighted sulfate mg/L as SO_4
Thickness-weighted		
AP.............	0.3050 (0.045)	0.1655 (0.183)
NP.............	0.2562 (0.078)	0.2785 (0.061)
NETNP..........	0.2225 (0.110)	0.2672 (0.070)
NP/AP..........	0.0701 (0.352)	0.2001 (0.136)
Volume-weighted		
AP.............	0.3580 (0.024)	0.0845 (0.326)
NP.............	0.4197 (0.009)	0.3701 (0.020)
NETNP..........	0.3799 (0.018)	0.3866 (0.016)
NP/AP..........	0.2096 (0.129)	0.2986 (0.051)

Acid Base Account

Net neutralization potential (NETNP, equal to the neutralization potential less the acid potential) was calculated for each overburden unit from each site using total sulfur data. Descriptive statistics are shown in Table 3. A wide range of acid-base properties were exhibited in the data set. Eighty-five of 264 individual strata were potential acid-producers according to the 5 ton/1000 ton neutralization deficit (NETNP<-5 tons/1000 tons) used for revegetation. Every site had at least one rock unit that met this criterion for acid potential, yet only 17 of the sites produced acidic drainage. Therefore, the presence of a stratum having NETNP<-5 tons/1000 tons was not a useful means to predict acidic drainage.

Post-mining alkalinity and sulfate concentrations were correlated with several acid-base account parameters (Table 4). The correlations generally were stronger when the acid base account values were aggregated by overburden volume rather than thickness. This is expected because the strata are represented more truly in the former aggregation even though the mine geometry assumptions were crude. Volume-weighted AP, NP, and NETNP were all significantly related to drainage net alkalinity, while only NP and NETNP were significantly related to drainage sulfate. Even when AP was calculated from pyritic sulfur values the correlation was not significant at the 5 pct level (unpublished data from this study). There was only a marginally significant relationship between sulfate concentration in the drainage and the value of NP/AP (r=0.29B6, p=0.051), intended to represent an oxidation potential inhibited by neutralization potential. All these correlations became insignificant (p=0.073 to 0.397) when the five sites having NETNP higher than 80 tons/1000 tons were excluded from the analysis. Including the acid and alkaline end-members of the set of all possible overburden compositions is expected to yield a higher correlation coefficient because overburden columns totally dominated by acid or alkaline strata produce analogous drainage quality. However, these correlations fail in the crucial hard-to-predict cases.

The significance of the correlations shown in Table 4 did not change markedly when AP and NETNP values were calculated using pyritic sulfur rather than total sulfur values. For example, the correlation coefficient for water alkalinity and thickness-weighted NETNP only increased from 0.2225 to 0.2262 when pyritic sulfur values were used. This finding results from the fact that pyritic sulfur and total sulfur contents in these samples were highly correlated. If we had only considered those cases where organic sulfur content was high and represented a variable fraction of total sulfur, AP and NETNP values based on pyritic sulfur rather than total sulfur would be expected to yield significantly stronger correlations.

Sulfate production in the reclaimed spoil may be affected by inherent differences in pyrite reactivity (Hammack 1988), availability of oxygen (Lusardi and Erickson), juxtapositioning of different rock units in the backfill and other factors. Splits of the samples from this study have been analyzed for thermal pyrite reactivity by evolved gas analysis and the data will be used to determine if an effective pyrite content (some combination of sulfur content and reactivity variables) can better predict drainage quality.

A scatterplot of drainage alkalinity versus volume-weighted NETNP (fig. 3) illustrated the lack of predictive value in this overburden variable alone. However, boundaries can be drawn to delineate the acid or alkaline character of the drainage. At NETNP values greater than 80 tons/1000 tons, all sites produced alkaline drainage. No such clear boundary was found on the acid end of the spectrum, probably because the data set did not include equally acid-dominated sites. Such sites usually fail to gain permit approval.

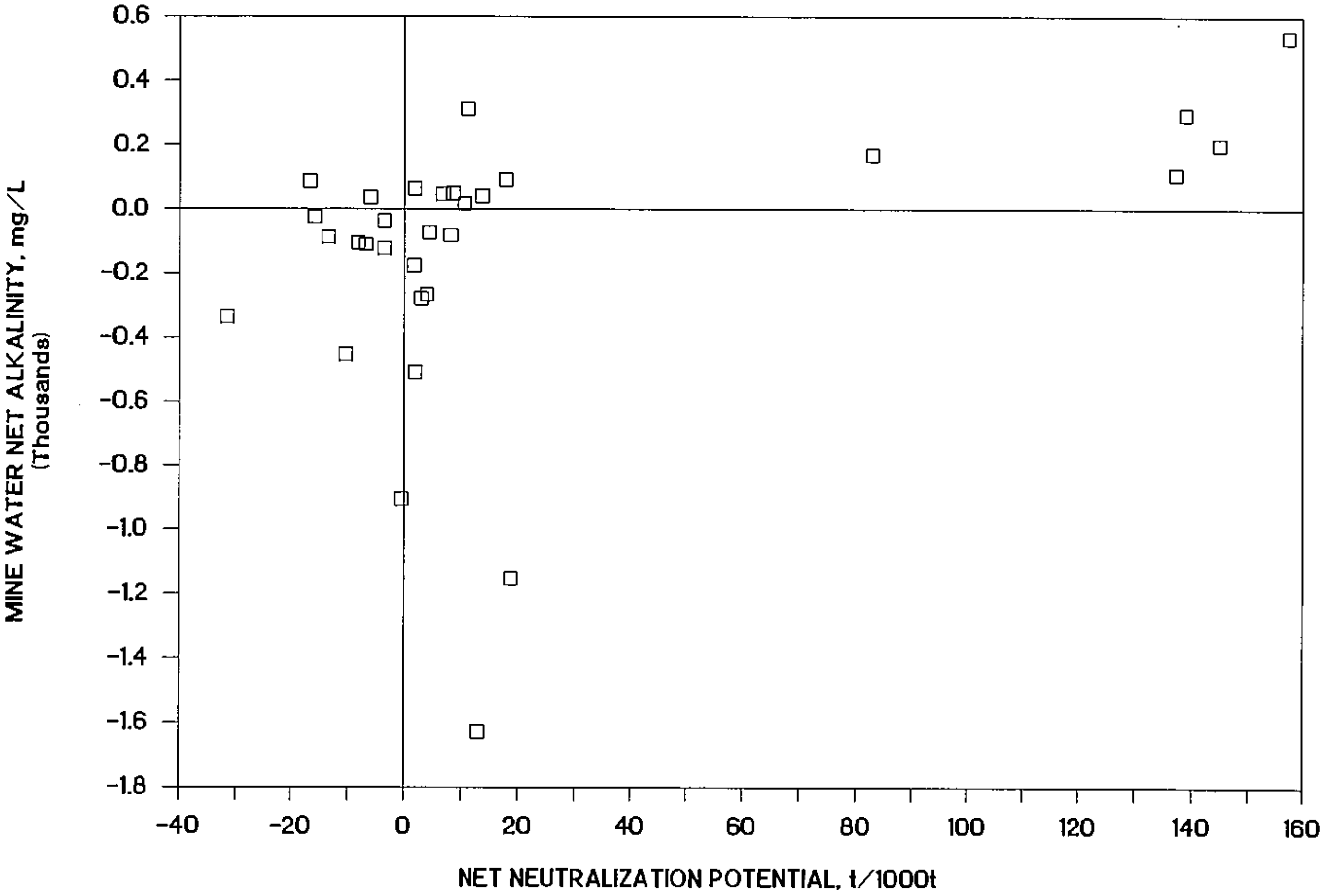

Figure 3.--Scatterplot of volume-weighted net alkalinity versus volume-weighted NETNP for all sites.

Intermediate boundaries are arbitrary:

0<NETNP<20:	acidic drainage in 8 of 15 sites
NETNP<10:	acidic drainage in 15 of 20 sites
NETNP< 0:	acidic drainage in 9 of 11 sites

Clearly, sites having volume weighted NETNP values lower than 20 tons/1000 tons were dominantly acid producers.

Simulated Weathering

The simulated weathering procedure was applied to all overburden samples from 18 of the study sites. Results of weathering tests, along with acid-base account results for the same sites are shown in Table 5.

Correlations were calculated that related weathering test parameters to actual drainage parameters (Table 6). The only significant relationship was between weathering sulfate and drainage sulfate (r=0.4059, p=0.046). These correlations suggest that the laboratory procedure somewhat simulated sulfate production as intended but failed to simulate subsequent neutralization processed that increase alkalinity and precipitate iron. As with the acid-base account, the direct correlation was not strong enough to predict post-mining drainage quality.

Failure to mimic the neutralization processes, and thereby predict drainage alkalinity and iron concentrations, could result from the laboratory tests being conducted on individual strata at atmospheric pCO_2 levels. Both elevated CO_2 and sequential positioning of alkaline and acidic strata affect the amount of carbonate minerals dissolved. No leachate sample exceeded 100 mg/L net alkalinity, while many post-mining drainage samples had net alkalinity in the range of 100 to 620 mg/L.

Samples from five of the study sites were also weathered in the laboratory as thickness-weighted composites of all overburden strata. Leachates from these combined samples sometimes exceeded 100 mg/L net alkalinity. While conclusions drawn from such a small data set are tenuous, this result suggests the intriguing possibility that neutralization reactions that occur in the field can be simulated in the laboratory if the neutralizing strata are exposed to leachate from acidic strata.

Table 5.—Summary of data for sites analyzed by the simulated weathering test[1]

Site ID	Post-mining Water Quality flow-weighted, mg/L		Pre-mining Data			
			Simulated weathering volume-weighted cumulative load, mg		Acid-base account volume-weighted tons/1000 tons	
	Alkalinity	Sulfate	Alkalinity	Sulfate	AP	NETNP
32	-1150.	4020.	-40.2	239.	5.54	18.8
14	-903.	1010.	7.66	48.3	7.31	-0.49
29	-509.	1430.	-41.6	106.	11.6	1.92
18	-453.	695.	-210.	208.	19.2	-10.4
12	-278.	1940.	2.08	37.5	2.35	2.99
19	-176.	819.	24.0	67.7	1.57	1.73
8	-109.	737.	-17.9	146.	13.0	-6.75
28	-81.3	741.	-4.69	57.5	6.75	8.18
4	-72.6	832.	17.6	54.8	15.0	4.38
21	-36.8	761.	26.5	108.	14.8	-3.54
31	64.8	258.	24.8	83.7	18.3	1.86
11	87.4	332.	-174.	281.	32.5	-16.8
6	91.7	797.	39.5	72.2	13.5	17.8
13[2]	109.	259.	22.7	27.1	1.47	7.25
5	170.	1040.	17.7	92.7	22.0	83.2
22	201.	2280.	-280.	995.	51.8	145.
25	313.	695.	20.7	199.	29.9	11.2
23	536.	3310.	41.6	315.	25.8	157.

[1] All values rounded to 3 significant figures or a maximum of 2 decimal places.

[2] Site 13 is thickness-weighted rather than volume-weighted.

Table 6.--Correlations between flow-weighted water quality parameters and simulated weathering test parameters.

Overburden variables, cumulative load, mg	Correlation coefficient (probability) Water variables, flow-weighted mg/L		
	Net alkalinity	Sulfate	Iron
Straight average			
Net alkalinity.....	-0.0436 (0.432)	0.1633 (0.259)	0.0193 (0.470)
Sulfate...........	0.2554 (0.153)	0.2308 (0.178)	-0.1680 (0.253)
Volume-weighted			
Net alkalinity.....	0.0880 (0.364)	-0.0861 (0.367)	-0.1033 (0.342)
Sulfate...........	0.2234 (0.186)	0.4089 (0.046)	-0.2276 (0.182)

CONCLUSIONS

The results of this study confirmed that the overburden analysis methods tested do not adequately predict post-mining drainage quality when used alone. This result is not surprising, as overburden analytical data is only one component of the pre-mining site assessment. Mine operators and regulatory authorities utilize other data and past experience in judging the environmental suitability of a proposed mine.

Examination of water quality data alone showed a high degree of temporal and lateral variability in contamination levels at a single site. Further, the data showed that pyrite oxidation was accompanied by varying degrees of neutralization. While these findings are consistent with the literature and fully expected, they serve to remind us that prediction of overall water quality from the whole mine system and prediction of individual seep water quality are two different things.

Results obtained from the acid-base account confirmed that the use of a 5 ton/1000 ton deficiency of neutralizers (NETNP < - 5 tons/1000 tons) to delineate acid-producing strata is invalid as a predictive tool. Each of the sites used in this study contained at least one lithologic unit that was potentially acid-producing by this standard. Yet only about half the sites produced acidic drainage.

Qualitative boundaries were found for the acid-base account to delineate the alkaline or acidic character of the overburden. All sites having a volume-weighted NETNP greater than 80 tons/1000 tons yielded alkaline drainage. In contrast, the majority of sites having a volume-weighted NETNP less than 20 tons/1000 tons yielded acid drainage. Unfortunately, no sites were found having NETNP in the range of 20 to 80 tons/1000 tons; this range is left as a gray area in predicting acidic or alkaline drainage. Additional data, already available in mining company and regulatory agency files, should be used to test and further refine these boundaries.

The weathering procedure used in this study failed to yield an accurate prediction of water quality and failed to delineate boundaries for drainage of differing acid/alkaline character. The correlation between sulfate produced during simulated weathering and sulfate concentrations observed in the field suggested that pyrite oxidation can be mimicked in the laboratory. Alkalinity-generating processes were not mimicked by this method. Limited data from laboratory weathering showed at least a potential for better simulation of neutralization processes when the overburden strata were composited into a single sample prior to weathering.

It is important to pursue improved means of predicting post-mining drainage quality because of the environmental and economic repercussions of incorrect predictions.

LITERATURE CITED

diPretoro, R. S. 1986. Premining prediction of acid drainage potential for surface coal mines in northern West Virginia. Master's thesis, West Virginia University, Morgantown, WV, 217 p.

Ferguson, K. D., and P. M. Erickson. 1987. Will it generate AMD? An overview of methods to predict acid mine drainage. In Proceedings, Acid Mine Drainage Seminar/Workshop, Halifax, Nova Scotia, Environment Canada, pp. 215-244.

Ladwig, K. J., and P. S. A. Campion. 1985. Spoil water quality variations at two regraded surface mines in Pennsylvania. In Proceedings, Symposium on Surface Mining Hydrology, Sedimentology, and Reclamation, University of Kentucky, Lexington, KY, pp. 121-130.

Lusardi, P. J., and P. M. Erickson. 1985. Assessment and reclamation of an abandoned acid-producing strip mine in northern Clarion County, Pennsylvania. In Proceedings, Symposium on Surface Mining Hydrology, Sedimentology, and Reclamation, University of Kentucky, Lexington, KY, pp. 121-130.

Smith, R. M., W. E. Grube, Jr., T. Arkle, Jr., and A. Sobek. 1974. Mine spoil potentials for soil and water quality. U.S. EPA Report EPA-670/2-74-070, 303 p.

Sobek, A. A., W. A. Schuler, J. R. Freeman, and R. M. Smith. 1978. Field and laboratory methods applicable to overburden and minesoils. U.S. EPA Report EPA-600/2-78-054.

U.S. Environmental Protection Agency. 1983. Methods for chemical analysis of water and wastes. EPA 600/4-79-020, 490 p.