The Use of Acid-Base Accounting to Predict Post-mining Drainage Quality On West Virginia Surface Mines

by

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Abstract Acid-Base Accounting (ABA) is an analytical tool to determine the acid- or alkaline-producing potential of overburden rocks prior to coal mining. This procedure was developed by Dr. Richard M. Smith and associates at West Virginia University in the late 1960s. After the passage of laws requiring an assessment of mining on water quality, ABA became the preferred method to predict post-mining water quality, and many permitting decisions for surface mines were and are based on the values determined by ABA. As a post-mining water quality predictor, ABA is best used as a qualitative assessment of the site's potential to produce acid mine drainage. Several studies have attempted to adapt ABA to a quantitative assessment of the site's post-mining water quality. By this approach, the mass of acid-producing rock is compared to the mass of alkaline-producing rock and a prediction of the water quality (amount of acidity or alkalinity) is obtained. Such analyses have given variable prediction success. We gathered information for 28 sites in West Virginia and estimated overburden amounts and ABA parameters on each site based on ABA data and topographic maps. Maximum potential acidity (MPA), neutralization potential (NP), net neutralization potential (NNP), and NP/MPA ratios were determined for each site based on ABA and correlated to post-mining water quality from springs or seeps on the mined property. On our 28 sites, total NNP varied from -12.7 to 106 tons per thousand tons (t/1000 t) and NP/MPA ratios varied from 0.2 to 21. We found no relationship between MPA with post-mining water quality, while NNP and NP/MPA ratio showed the best correlation. Six sites gave NP/MPA ratios of <1; four of them (67%) gave net acid post-mining water quality, while the other two sites were only slightly net alkaline. Five sites had NP/MPA ratios of 1.1 to 1.6, and only one of these sites had net acid water quality and only slightly so. The remaining 17 sites had NP/MPA ratios >2.2 (all of which should produce alkaline water) and three of the 17 sites produced acid drainage. Two sites with NP/MPA ratios of <1 gave net alkaline water, while 18 out of 22 sites (82%) with NP/MPA ratios >1 gave net alkaline water quality. ABA is a good tool to assess overburden quality before mining and to predict post-mining drainage quality after mining. Most sites followed the prescribed patterns of prediction.

Additional Key Words: Acid Mine Drainage, Neutralization Potential, Overburden Analysis, Potential Acidity, Pre-mining Planning

Introduction

Most coal mining state regulatory agencies began requiring the prediction of acid- and alkaline-producing materials in the overburden of surface mine operations in the early 1970s. For example, in 1971 the West Virginia legislature passed a law requiring mine operators to show in the permit "the presence of any acid-producing materials, which, when present, may cause minesoils with a pH of less than 3.5 and prevent effective revegetation" (West Virginia Surface Mining Law, 1971). Dr. Richard M. Smith and his associates at West Virginia University, in conjunction with the West Virginia coal regulatory agency, began working on a procedure for identifying acid-producing materials in 1965 (Perry, 1998). Throughout the late 1960s and 1970s, the procedure was refined and termed "Acid-Base Accounting" (ABA) by Dr. Smith and his students (Smith et al., 1976). ABA was originally designed to distinguish layers in the overburden that could be used as topsoil substitutes or as hard durable rock for valley fills. But since the method identified acid- and alkaline-producing materials in the overburden, this method was the first technology available to predict the

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quantity of acid-producing materials prior to mining (Skousen et al., 1990). Since the late 1970s and the passage of the Surface Mining Control and Reclamation Act of 1977, ABA has become widely adopted as a method of overburden characterization and prediction of post-mining drainage quality (Sobek et al., 2000).

ABA, as originally developed, is designed to measure Neutralization Potential (NP) and sulfur content of individual overburden strata. From these measurements, Maximum Potential Acidity (MPA) and Net Neutralization Potential (NNP) of each geologic layer down to, including, and immediately underlying the coal seam can be calculated. The NP is a measure of the amount of neutralizing compounds (mostly carbonates and exchangeable bases) present in the coal and overburden. The first step in NP determination is the addition of 1-2 drops of 25% HCl to a small amount of prepared sample. The degree of reaction is then observed and recorded as 0 (none), 1 (slight), 2 (moderate), or 3 (strong). Based on the fizz test results, an appropriate amount and strength of HCl is added to a 2-g sample of rock and boiled for 5 minutes. After cooling, the solution is then titrated with NaOH to pH 7.0. The NP is calculated from the amount of acid neutralized by the sample and is expressed in tons/1000 tons (t/1000 t) of overburden (Kania, 1998). Refinements have been made recently on the NP method to discount alkalinity from slower-reacting minerals such as siderite (Skousen et al., 1997).

The MPA is the maximum amount of sulfuric acid that can be produced from the oxidation of sulfur minerals in the coal and overburden. Although acid production is associated with pyritic sulfur, MPA determinations typically measure total sulfur because it currently provides the easiest basis for calculating MPA (Kania, 1998). The simplest and most frequently used method of total S determination is high-temperature furnace combustion. In this process, the sample is heated to approximately 1350° C while a stream of oxygen is passed over the sample. The sulfur dioxide (SO_2) that is released can then be measured using an Automated Sulfur Titrator or infrared absorption (Skousen, 2000). This test results in a percent of sulfur present in the rock and is then multiplied by either 31.25 or 62.5 to determine the MPA in t/1000 t. These numbers are based on the following stochiometry of pyrite oxidation:

$$FeS_2 + 2CaCO_3 + 3.75O_2 + 1.5H_2O \rightarrow Fe(OH)_3 + 2SO_4^{-2} + 2Ca^{+2} + 2CO_2 \quad (1)$$

In this equation, 1 mol of FeS_2 (64 g of sulfur) is neutralized by 2 mols of $CaCO_3$ (200 g of $CaCO_3$). Therefore, it takes 31.25 tons of $CaCO_3$ to neutralize 1000 tons of rock containing 1% pyritic sulfur. Cravotta et al. (1990) suggested that in a closed system (such as that of a surface mine backfill) CO_2 would not be driven off in the reaction, but would instead react with water to form carbonic acid as in the following reaction:

$$FeS_2 + 4CaCO_3 + 3.75O_2 + 3.5H_2O \rightarrow Fe(OH)_3 + 2SO_4^{-2} + 4Ca^{+2} + 4HCO_3^{-} \quad (2)$$

In this reaction, 1 mol of FeS_2 is neutralized by 4 mols of $CaCO_3$. Here 1000 tons of rock containing 1% pyritic sulfur requires 62.5 tons of $CaCO_3$ for neutralization. Studies analyzing ABA have used both methods. The results have been mixed (Brady and Cravotta, 1992; Brady et al., 1994). In general, the 31.25 factor for overburden MPA calculation is most commonly used.

After the NP and MPA are calculated using the above methods, total Net Neutralizing Potential (NNP) can be determined for each stratigraphic layer by subtracting the MPA from the NP. Conceptually, a positive number indicates potentially alkaline-producing strata and a negative number indicates potentially acid-producing strata. This number can then be used to identify potentially toxic materials in the overburden and can assist in planning overburden handling and placement (Skousen et al., 1987).

The interpretation of ABA data for use in predicting post-mining water quality involves numerous assumptions. First, all sulfur in a sample will react to form acid. Second, all material in the sample that consumes acid in the laboratory will generate alkalinity in the field. Third, the reaction rate of sulfur will be equivalent to the dissolution rate of the neutralizing material. And fourth, NP and %S below certain thresholds do not influence water quality. It is unrealistic to believe that these assumptions are correct in the natural environment and therefore many researchers have questioned the ability of ABA to accurately predict post-mining drainage quality (diPretoro and Rauch, 1988; Erickson and Hedin, 1988). In addition, there is uncertainty as to which ABA parameters most accurately estimate acid- or alkaline-production potential.

In the initial usage of ABA as a predictor of post-mining water quality, overburden calculations were made only according to layer thickness, giving equal weight to layers at the top and bottom of the column. However, in most surface mines of West Virginia and Pennsylvania, the topography is hilly to mountainous with horizontal strata. So, a 5-foot-thick rock stratum high up in the overburden contains much less volume of material than a 5-foot-thick rock stratum low in the

Table 1. Sites, locations and descriptions of surface mine sites used in this study for Acid-Base Accounting evaluation.

Site Ref	County	Method	Acres	Coal Seam	Dainage Quality
Al	Clay	Contour	27	Mid Kit	Net acid
AR	Webster	Contour	87	UF, Mid/Up Kit	Net alkaline
Bf	Preston	Contour	18	UF	Net acid
BN	Monongalia	Contour	17	Waynesburg	Net alkaline
CF	Monongalia	Contour	10	Waynesburg	Net acid
CH1	Monongalia	Contour	33	Waynesburg	Net alkaline
CH2	Monongalia	Contour	143	Waynesburg	Net alkaline
Cr	Preston	Contour	4	UF	Net acid
D2	Preston	Contour	15	UF	Net acid
DC	Grant	Contour	91	UF	Net alkaline
EE	Preston	Contour	38	UF	Net acid
FM	Preston	Coutour	116	LF, UpK	Net alkaline
F2	Kanawha	Mtntop	96	5&6 Block, UpK	Net alkaline
GF	Preston	Contour	7	UF	Net alkaline
HG	Webster	Contour	206	UF, Mid/Up Kit	Net alkaline
HP	Lewis/Upshur	Contour	18	Redstone/Pitt	Net acid
Id	Preston	Contour	5	Bakerstown	Net alkaline
IL	Preston	Contour	9	UF	Net acid
KE	Monongalia	Contour	153	Waynesburg	Net alkaline
L2	Fayette	Contour	78	Alma-Eagle	Net alkaline
MC	Nicholas	Contour	70	Gilbert, Eagle	Net alkaline
ME	Monongalia	Contour	60	Sewickley, Red	Net alkaline
NA	Mineral	Area	21	Bakerstown	Net alkaline
OS	Monongalia	Contour	37	Waynesburg	Net alkaline
PM	Fayette	Contour	18	Glenalum Tunnel	Net alkaline
PR	Clay	Contour	7	UpK	Net alkaline
St	Preston	Contour	21	Bakerstown	Net alkaline
TM	Nicholas	Contour	83	Up/Mid K, 5Bl	Net alkaline

stratigraphy. Therefore, this method overestimated the amount of alkaline material high in the overburden column, and created a situation where insufficient alkaline material was available for neutralization of acidity in high-sulfur rocks near the coal seam. Some of these sites were mined and subsequently generated severe, post-mining acid mine drainage due to inaccurate overburden interpretation. In the early 1980s, computer spreadsheets came into use for the input and volume adjustment of ABA data. These spreadsheets made it easier to calculate ABA parameters and to weight them based on overburden layer thickness and aerial extent of each layer. Therefore, subsequent ABA calculations included volume estimates for each layer, making it easier to evaluate total volumes of alkaline- or acid-producing materials (Smith and Brady, 1990).

In 1988, two studies by diPretoro and Rauch (1988) and Erickson and Hedin (1988) compared volume-weighted ABA data with post-mining water quality. Due to the difficulty of measuring the aerial extent of each stratigraphic layer, precise volumetric calculations were not performed. In both studies, volume-weighted values were calculated by assuming a right triangle-shaped area to be mined. Although this method can only be considered as an approximate technique for volumetric adjustment, it yielded better results than simple thickness methods of the past.

A 1994 study by Keith Brady and his associates at the Pennsylvania Department of Environmental Protection (PADEP) developed a method of ABA calculation using actual measurements of the areas to be mined (Brady et al., 1994). Due to the impracticality of measuring the acreage of each individual stratum, only the acreage of the upper and lower strata was measured. A computer spreadsheet then interpolated the acreage of each stratigraphic layer between the two, assuming a constant slope. Volumes were calculated for each interval using this acreage and the measured thickness (Smith and Brady, 1990). This PADEP study took ABA calculations one-step further by determining the mass of each individual layer, which was calculated from the unit weight of the rock type present in the strata. MPA and NP were then expressed in tons.

Even though both of these methods, volume-weighted and mass-weighted, yielded more accurate ABA measures than previous methods, the question remained as to which ABA parameters best predicted post-mining water quality. In studies by diPretoro and Rauch (1988), Erickson and Hedin (1988) and Brady et al. (1994), NP and NNP were found to be the best indicators of post-mining drainage quality. diPretoro and Rauch (1988) found that sites with NP >40 t/1000 t (or parts per thousand) and NNP >30 t/1000 t produced net alkalinity in post-mining drainage. Erickson and Hedin (1988) compared the net alkalinity of post-mining water to NNP and found that NNP >80 produced alkalinity and NNP <20 typically produced acidity. It should be noted that this study had no sites with NNPs between 20 and 80 t/1000 t. A mass-weighted study by Brady et al. (1994) resulted in NP and NNP values much lower than earlier studies. In this study, sites with NP >21 t/1000 t and NNP >12 t/1000 t produced alkaline drainage.

In addition to NP and NNP, the ratio of NP to MPA may also be a reliable indicator of post-mining water quality. The ratio is calculated by dividing the total NP of the entire overburden column by the MPA of the entire overburden column. diPretoro and Rauch (1988) found that sites with a NP/MPA ratios of <2.4 generally resulted in acid mine drainage and sites with >2.4 usually produced alkaline drainage.

Although all three studies identified the importance of NP and NNP in prediction of post-mining water quality, all three designated different numbers and ranges of NP and NNP to predict post-mining water quality. Also, these ranges only represented trends in the relationship of NP and NNP to water quality prediction, and all sites did not fit the predictions. For these reasons, further examination of ABA data with more sites is needed in the prediction of post-mining water quality.

This study collected ABA information and permit maps from 28 surface mined sites in West Virginia to determine MPA, NP, NNP and NP/MPA ratio based on precise mass-weighted calculations of overburden materials. These ABA parameters were then compared with post-mining water quality to determine which parameters most accurately predicted post-mining water quality.

Methods

Selection of Sites

Study sites (Table 1) were chosen to represent surface mining operations throughout the state of West Virginia. No special consideration was given to the surface mining area, coal seam, mining method, special handling plans, or past post-mining water quality. In all sites, special handling plans were not considered and estimates were based on overburden properties only from drill cores and ABA calculations. If alkaline addition was practiced, the amount of material was added to the overall NP of the site.

Sites were selected from mine operator files or from surface mine permits on file with the WV Division of Environmental Protection. To ensure the most accurate ABA calculations and evaluations, each site had to meet the following five criteria. First, detailed maps were needed to show the boundaries of mining, location of core holes, coal outcrops, depth of overburden, and post-mining water sampling points. Second, a complete ABA data set was required from overburden cores drilled above or near the highest point of mining (ABA data must include depth, thickness, rock type, %S and NP for all layers down to and including the coal pavement). Third, we needed to know the amounts of alkaline addition used during mining. Fourth, we wanted a data included flow, pH, alkalinity, acidity, iron, aluminum, and manganese. Twenty-five sites had data for at least five separate sampling times. The number of samples ranged from 5 to 13 water quality samples and the acidity/alkalinity values were averaged to determine the net alkalinity value of post-mining discharge quality for each site. Most of the sites (18 of 28) had post-mining water data taken from two to five years after completion of the mining, 8 sites had water sampled between 5 and 15 years after completion, and two sites had water quality taken more than 15 years after completion. Only one water sample had been taken at three of the 28 sites, and each of these was taken and analyzed in the fall of 2000. Other records and regulatory personnel were contacted to ascertain that these one-time samples represented the water quality on the site.

Volume Calculations

Volumes of each layer were determined from actual measured areas and basic geometry (Figure 1). Sites with complex topography were divided into sections of similar width, depth and slope. Each section was then measured for length, average width and average depth and recorded. These measurements were then used to perform volume calculations for each rock layer present in the sections. Due to the topography of the land area and the horizontal nature of the geologic layers, each section was treated as a right triangle and volume calculations were performed using a geometric approximation method similar to the one first described by diPretoro and Rauch (1988). However, unlike volumetric calculations of the past, which determined the percentage of the overburden occupied by each stratum, this study calculated actual volumes of each layer using measured width, depth and slope of the mined area and thickness of each rock layer. From these measurements, the width of each layer (the horizontal distance from the highwall to the sloping surface) could then be calculated using the following equation:

$$\text{Width} = \tfrac{1}{2}(w_2 - w_1) \quad (3)$$

Volumes of each layer could then be calculated from the thickness, width and length (distance along the highwall) in the following manner:

$$\text{Total Volume} = (t * \tfrac{1}{2}(w_2 - w_1) * l) \quad (4)$$

Where t = thickness,
w_1 = width from the highwall to the outslope at the top of the rock layer,
w_2 = width from the highwall to the outslope at the bottom of the rock layer,
l = length along the highwall.

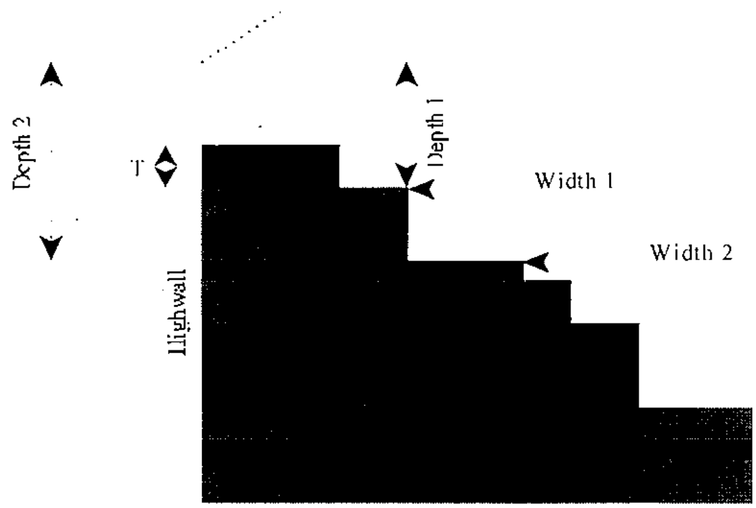


Figure 1: Units for the triangular approximation of volnme calculations.

Mass Calculations

Volumes were then converted to mass by multiplying the volume of each stratigraphic unit by the unit weight (Tons/Ac-ft) of the rock type present.

$$\text{Volume (ft}^3\text{)} * \frac{\text{Acre}}{43560\ \text{ft}^2} * \frac{\text{Tons}}{\text{Acre-ft}} = \text{Tons Overburden} \quad (5)$$

Although there is some difference of opinion as to the most accurate estimates of unit weight, the weights used here are given in Table 2.

The tons of overburden present in each layer is easily used to convert %S and NP into MPA and NP (both in tons) in the following manner:

$$\text{Tons Overburden} * \frac{(\%S * 31.25)\ \text{Tons}}{1000\ \text{Tons Overburden}} = \text{Tons MPA} \quad (8)$$

$$\text{Tons Overburden} * \frac{\text{Tons NP}}{1000\ \text{Tons Overburden}} = \text{Tons NP} \quad (9)$$

Table 2. Unit weight (tons/ac-ft) of rocks used in this study to calculate volumes and tonnage of overburden materials (Caterpillar, 1991).

Rock Type	Unit Weight (Tons/Ac-ft)
Soil	2037
Sandstone	3152
Shale	3623
SS/SH	3388
Mudstone	3658
Limestone	3549
Coal	1845

Development of Spreadsheet

Due to the nature of volume and mass calculations, we developed a computer spreadsheet to expedite the process similar to one mentioned by Smith and Brady (1990). This Simmons & Skousen (S&S) spreadsheet is a modification of the Pennsylvania spreadsheet developed by the PADER. Equations in the spreadsheet are identical to the volume and mass calculations outlined in the previous section of this paper. Sites with complex topography can be divided into sections of similar width, depth, and slope. The addition of any alkaline materials can be added to the total NP. Total overburden, MPA, NP, NNP and NP/MPA ratio are calculated for the entire site and reported in a summary table in tons and in tons per thousand tons (t/1000 t) overburden.

Results and Discussion

Table 1 lists the 28 sites in alphabetical order and provides information on the location, size, coal seam mined, and the net drainage quality of each site. Nine of the 28 sites are found in southern West Virginia (Clay, Fayette, Kanawha, Nicholas, and Webster Counties). The remaining 19 northern West Virginia sites include nine sites in Preston, seven sites in Monongalia, and one each in Lewis/Upshur, Mineral, and Grant Counties.

The coal geology of West Virginia is divided into the northern and southern coalfields, both of which were formed during the Pennsylvanian System (Barlow, 1974). The southern coalfield contains coal seams found in the Pottsville Group (Pocahontas, New River, and Kanawha Formations), which generally have higher overall quality (higher rank and heating value) and lower sulfur and ash contents than northern coals. The northern coalfield contains coal seams in the Allegheny, Conemaugh, and Monongahela Groups, which are generally high in sulfur and ash content. The high sulfur content of the coal and associated rocks in the northern coalfield makes mining of these coals prone to acid mine drainage generation. The dividing line between coalfields is the hinge line.

The geology in the northern coalfield is also separated by the amount of carbonate or calcareous material in the rocks. The eastern section of the northern coalfield is characterized by low amounts of calcareous material or limestone in the strata, while the western section may have limestone or other alkaline-producing rocks associated with coal seams. Smith et al. (1976) separated these unique geologic settings into "surface mining provinces" (SMP). SMP 1 occurs in southern WV and is comprised of low sulfur and low carbonate rocks. SMP 2 occurs in the eastern section of the northern coalfield and contains coals and associated rocks with high sulfur and low carbonate content. SMP 3 is found in the western section of the northern coalfield with rocks containing high sulfur and high carbonate content.

The size of these operations varied between 4 and 206 acres. Coal seams extended from the Alma coal seam found in the Pottsville Group (New River and Kanawha Formations) to the Waynesburg coal seam at the top of the Monongahela Group (Table 3).

Table 3. Coal seams represented in the West Virginia Acid-Base Accounting Study.

Group	Coal Seam	Number of Sites
Monongahela	Waynesburg	6
	Sewickley-Redstone	1
	Pittsburgh-Redstone	1
Conemaugh	Bakerstown	3
Allegheny	Upper Freeport only	7
	Freeports + Kittannings	3
	Kittannings (5-Block) only	4
Kanawha	Alma-Eagle, Glenalum Tunnel	3

Eight of the 28 sites gave net acid water. We did not specifically select northern West Virginia sites, but we were interested in sites that produced acid mine drainage, and very few sites after mining and reclamation in southern West Virginia produce net acid water quality. The areas in Grant, Mineral, Preston, and eastern Monongalia Counties are also of much interest in our study because the coal and overburden geology varies greatly in SMP 2. The mined overburdens for the coal seams within the Allegheny, Conemaugh, and Monongahela Groups (i.e., the Kittannings, Freeports, Bakerstown, and Pittsburgh coal seams) can produce either acid or alkaline mine drainage depending on the dominant overburden types on that specific site.

Of the eight sites that gave net acid water, five were from Upper Freeport surface mines in Preston County. However, one Preston County Upper Freeport mine in our study produced net alkaline water. Two operations in Preston County mined the Bakerstown coal, which produced alkaline post-mining water quality, and the other site in this county was an alkaline-producing Kittanning surface mine.

Table 4 summarizes the calculations from conducting our overburden volume and mass analyses based on permit map topography, mine size, and overburden cores. From these values,, the NP/MPA ratio for each site was calculated. Table 4 lists the sites according to NP/MPA ratio with lines separating NP/MPA ratios <1, 1-2, 2-4, and >4.

The prevailing thought is that sites with overburden NP/MPA ratios of <1 should produce acid mine drainage, while ratios of >2 should produce net alkaline drainage. Those between 1 and 2 could generate either acid, alkaline, or neutral drainage (Perry, 1998). In our study, six sites had NP/MPA ratios of <1, and four of these sites produced net acid water (Table 4). The two sites that were not acid producers were from Fayette and Clay Counties (southern WV) and both had very low total MPA and total NP, and had only slightly negative NNP. All ABA values for these two sites suggest that the overburden would not affect water quality significantly, and indeed the water quality is only slightly alkaline.

Of the five sites that gave NP/MPA ratios between 1 and 2, only one produced net acid water, and only slightly so. This site was a Middle Kittanning mine in Clay County. The other four sites with NP/MPA ratios between 1 and 2 were from Preston County (one Upper Freeport site and one Bakerstown site), Monongalia County (a Waynesburg site), and Nicholas County (southern WV site).

Seventeen of the 28 sites had NP/MPA ratios >2. Of these sites, three produced net acid water. The Cr, D2, and HP sites had NP/MPA ratios of 2.2, 3.6, and 8.9, respectively. It is hard to conceive that ratios of 3.6 and especially 8.9 could produce acid drainage. Two of the sites were from Upper Freeport Preston County mines (Cr and D2), while the other was a Pittsburgh/Redstone coal mine from Lewis/Upshur County (HP). The Cr site was mined relatively slowly with the surface mine pits remaining open for long periods (personal communication from past inspectors and operators). Perry et al. (1997) noted that acid mine drainage was reduced on potentially acid-producing sites when mining and reclamation was done quickly. Reclaiming disturbed areas prone to acid mine drainage quickly decreases the amount of time pyritic material is exposed to oxidation and weathering. The slow mining of the Cr site may have allowed excessive oxidation of pyritic materials, thereby creating a larger problem with acid drainage than if the site had been mined more quickly.

The D2 site produced net acid drainage for the first seven years after mining and reclamation, but has been producing alkaline drainage for the past two years. It seems that acid salts in the overburden were released quickly as water moved through the backfill. Over time, as the salts were leached and no more acid was generated, the acid drainage has been gradually overcome by the alkaline-producing potential of the backfill material. The HP site is only slightly acidic with primarily manganese in the water. It is not believed that deep mine drainage contributed to the drainage flowing from any of these three surface mines, nor does it appear that refuse was placed on the site or any other unusual reclamation practice caused an otherwise alkaline-producing site to generate acid drainage.

Figures 2 through 5 are graphs of some of the ABA overburden parameters versus net alkalinity of post-mining water quality. Figure 2 showed no relationship between MPA in t/1000 t and net alkalinity of post-mining water. Acid mine drainage occurred on sites with very low MPA (2.7 t/1000 t) to high MPA (20.1 t/1000 t). But alkaline drainage occurred on sites with 22.6, 23.3, and 27.9 t/1000 t MPA. So the critical parameter for post-mining water quality prediction was not total sulfur or potential acidity calculated from total sulfur measurements. Brady et al. (1994) similarly found no relationship between MPA and post-mining water quality.

Researchers have related that total NP in the overburden of a surface mine is a good predictor of post-mining water quality (Brady et al., 1994; Perry and Brady 1995). Figure 3 shows total NP versus net alkalinity in post-mining water on our 28 sites. Thirteen sites had total NP <20 t/1000 t with eight of these sites having alkaline water (61%) and five having acid water (39%). Three sites out of 15 with NP >20

Table 4. Summary of Acid-Base Accounting sites with size, location, overburden amounts, NP/MPA ratios and accompanying post-mining water quality. Sites are sorted by NP/MPA ratio.

Site Ref	Acres	County	Coal Seam	Overburden (tons)	Total MPA (tons)	Total MPA (t/1000 t)	Total NP (tons)	Total NP (t/1000 t)	Total NNP (tons)	Total NNP (t/1000 t)	NP/MPA	Net Alkalinity mg CaCO3/L
Bf	18	Preston	UF	1028776	16390	15.9	3304	3.2	-13086	-12.7	0.2	-277
CF	10	Monongalia	Waynesburg	1143720	10645	9.3	4706	4.1	-5939	-5.2	0.4	-70
EE	38	Preston	UF	22418	45152	20.1	23071	10.3	-22081	-9.8	0.5	-432
PM	18	Fayette	Glenalum Tunnel	1173788	2751	2.3	1707	1.5	-1044	-0.9	0.6	12
IL	9	Preston	UF	718353	5695	7.9	4037	5.6	-1658	-2.3	0.7	-35
PR	7	Clay	UpK	556994	5158	9.3	4097	7.4	-1061	-1.9	0.8	5
GF	7	Preston	UF	360156	3210	8.9	3498	9.7	287	0.8	1.1	78
Al	27	Clay	Mid Kit	2157463	5756	2.7	6719	3.1	963	0.4	1.2	-15
MC	70	Nicholas	Gilbert, Eagle	6022448	21450	3.6	31318	5.2	9868	1.6	1.5	35
CH2	143	Monongalia	Waynesburg	15258418	345005	22.6	535308	35.1	190303	12.5	1.6	151
Id	5	Preston	Bakerstown	244912	6835	27.9	11084	45.3	4249	17.4	1.6	117
Cr	4	Preston	UF	143591	2607	18.2	5823	40.6	3216	22.4	2.2	-59
KE	153	Monongalia	Waynesburg	21498339	500730	23.3	1289735	60	789005	36.7	2.6	86
F2	96	Kanawha	5&6 Block, UpK	42182989	226151	5.4	590705	14	364554	8.6	2.6	43
HG	206	Webster	UF, Mid/Up Kit	80100291	327679	4.1	1039592	13	711913	8.9	3.2	95
CH1	33	Monongalia	Waynesburg	5218549	67384	12.9	226710	43.4	159326	30.5	3.4	136
D2	15	Preston	UF	3027525	28984	9.6	104559	34.5	75575	25	3.6	-16
FM	116	Preston	LF, UpK	19377158	179142	9.2	699318	36.1	520176	26.8	3.9	23
OS	37	Monongalia	Waynesburg	6941278	97003	14	396332	57.1	299329	43.1	4.1	136
NA	21	Mineral	Bakerstown	3502940	27034	7.7	153473	43.8	126439	36.1	5.7	2
ME	60	Monongalia	Sewickley, Red	15469976	214311	13.9	1370175	88.6	1155864	74.7	6.4	40
L2	78	Fayette	Alma-Eagle	31630198	47769	1.5	309510	9.8	261741	8.3	6.5	60
DC	91	Grant	UF	19415286	75618	3.9	496137	25.6	420519	21.7	6.6	115
TM	83	Nicholas	Up/Mid K, 5Bl	15496427	14863	1	103290	6.7	88427	5.7	7	21
BN	17	Monongalia	Waynesburg	2734553	27312	10	216741	79.3	189428	69.3	7.9	331
HP	18	Lewis/Upshur	Redstone/Pitt	1527556	7936	5.2	70781	46.3	62845	41.1	8.9	-17
AR	87	Webster	UF, Mid/Up Kit	35483102	103815	2.9	1026349	28.9	922535	26	9.9	228
St	21	Preston	Bakerstown	2849661	15142	5.3	317160	111.3	302018	106	21	140

Figure 2. MPA vs Net Alkalinity

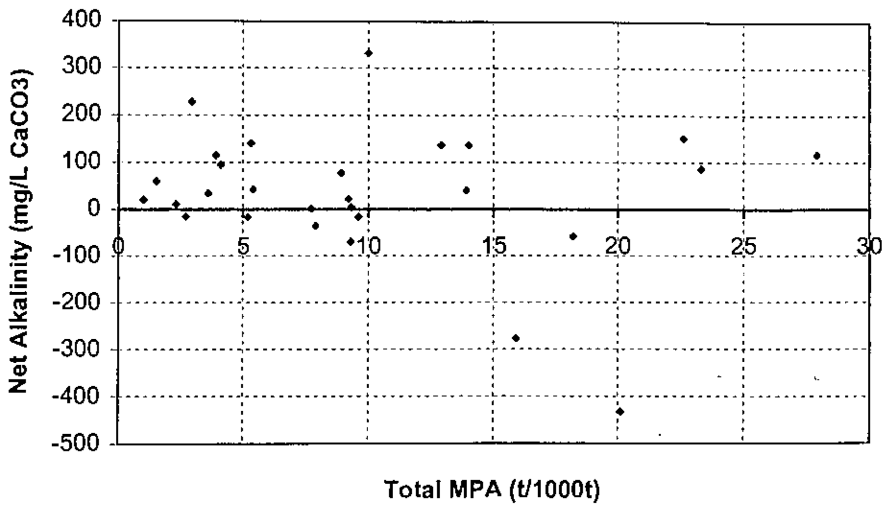


Figure 3. Total NP vs Net Alkalinity

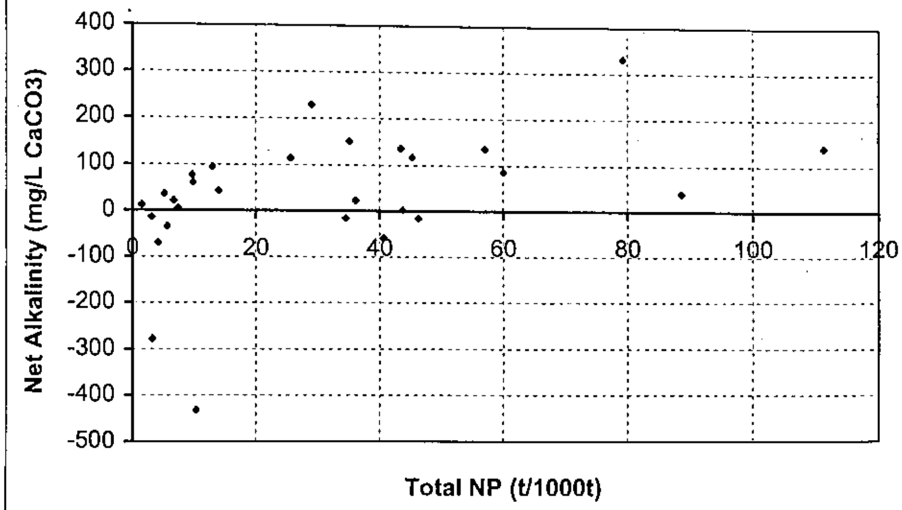


Figure 4. Total NNP vs Net Alkalinity

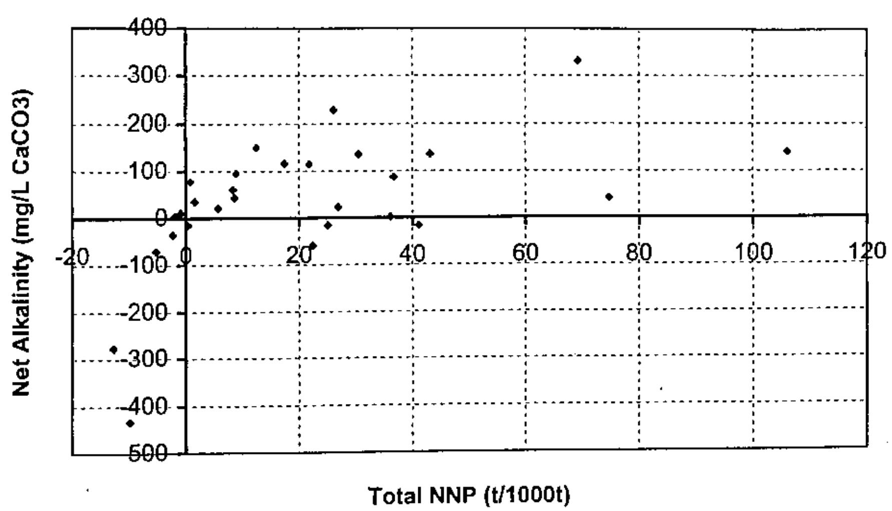
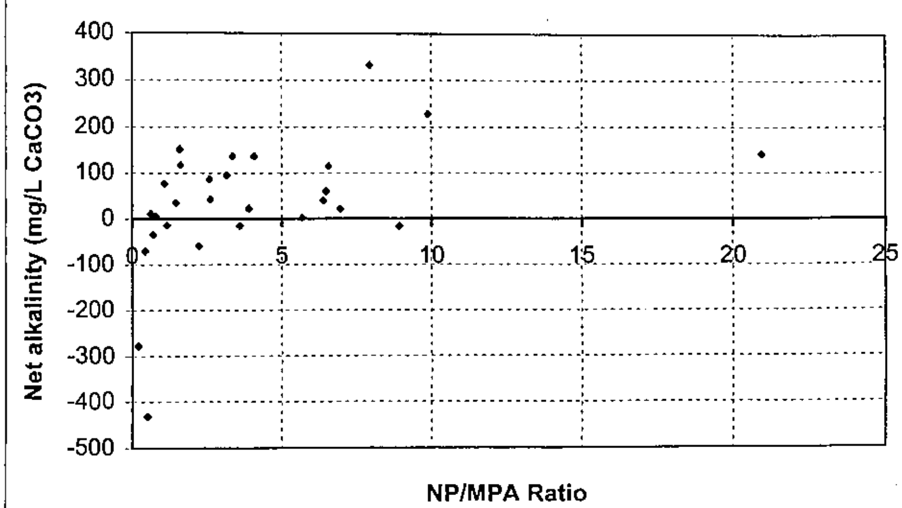


Figure 5. NP/MPA Ratio vs Net Alkalinity



t/1000 t (20%) gave acid drainage, and two of these sites had total NP >40 t/1000 t. Therefore, 80% of sites with NP >20 t/1000 t gave alkaline drainage. If the three problematic sites (Cr, D2, and HP) are removed from the list, then all the net acid sites had an NP <10 t/1000 t. From our data, NP was not a clear indicator of post-mining water quality, but perhaps these three NP ranges (<20, 20-40, and >40) can be used as general guidelines as originally stated by dePretoro and Rauch (1988).

Total NNP combines MPA and NP into one variable, which was plotted against net alkalinity (Figure 4). Past predictions have used >5 or >12 NNP (Brady et al., 1994; Perry and Brady, 1995), >15 NNP (Skousen et al., 1987), and >30 NNP (diPretoro and Rauch, 1988) as values that should produce net alkaline water. Values of <5 NNP (Brady et al., 1994; Perry and Brady, 1995; Skousen et al., 1987) and <10 NNP (diPretoro and Rauch, 1988; Erickson and Hedin, 1988) have been used as predictors of acid drainage.

In our data, those sites with high negative NNP values (<-2.3 NNP in Table 4) gave acid drainage, while five other sites with nearly neutral NNP values (-1.9 to 1.6) gave slightly acidic or alkaline drainage. Three sites (the same problematic sites as noted above), all with >20 NNP, produced acid drainage (-59 to -16 net alkalinity). Again, if these three sites are excluded, all of the acid sites had NNP <0.4 t/1000 t.

Figure 5, plotting NP/MPA ratio against net alkalinity, shows the same trend as NNP versus net alkalinity. The same three sites with acid water and high NP/MPA ratios are apparent on this graph, while the other five acid sites fit the general prediction pattern of NP/MPA ratios of <1 producing acid drainage. So, in general, an NP/MPA ratio of <1 will produce mostly acid drainage sites, between 1-2 will produce mostly alkaline drainage sites, while NP/MPA ratios of >2 will produce alkaline drainage with some exceptions.

We wondered if any relationship existed between the size of the mine (equating to total tons of overburden moved) and net alkalinity of post-mining water. All 11 sites >50 acres gave alkaline water, while eight of the 17 sites <50 acres in size gave acid water (Table 4). Small mines move less overburden and therefore have less chance of intercepting calcareous strata.

Summary and Conclusions

Acid-base accounting has been adopted to help in the prediction of post-mining water quality on surface mines. Twenty-eight sites were selected from West Virginia Division of Environmental Protection (WVDEP) files and from operator files. Permit boundaries from topographic maps were obtained along with overburden core information to estimate the amounts of overburden moved on each site and the amounts of neutralizing and acid-producing material. From these estimates, total MPA, NP, NNP and NP/MPA ratios were determined. Post-mining water quality was obtained from WVDEP files or was determined by our sampling and analysis.

Six sites from our pool of 28 sites had NP/MPA ratios of <1, and four of these six sites (67%) produced acid drainage. The two remaining sites with NP/MPA ratios <1 were from southern WV and produced only slightly alkaline drainage.

Five of the 28 sites had NP/MPA ratios of between 1 and 2, and only one site of these five (20%) produced acid drainage, and only slightly so. Seven sites had NP/MPA ratios between 2 and 4, and two of the seven sites produced acid drainage (29%). Combining these two categories (NP/MPA ratio between 1 to 4) gives 3 acid sites out of 12 total (25% acid sites). Ten sites out of 28 had NP/MPA ratios >4, and one of these sites (10%) produced slightly acid water.

From these data, all sites in northern West Virginia (four sites) with a NP/MPA ratio <1 produced acid drainage. For all sites with an NP/MPA ratio >1, 18 out of 22 (82%) produced alkaline drainage, and only one site with an NP/MPA ratio of >1 (Upper Freeport Preston County mine) gave post-mining net acid water above 50 mg/L. The other three net acid sites with NP/MPA ratios >1 produced only slightly acid water (-15 to -17 mg/L acidity).

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Literature Cited

Barlow, J.A., 1974. Coal and coal mining in West Virginia. Coal Geology Bull. No. 2. West Virginia Geological and Economic Survey, Morgantown, WV.

Brady, K.B.C. and C.A. Cravotta III, 1992. Acid base accounting: an improved method of interpreting overburden chemistry to predict quality of coal mine drainage. In: Proceedings: Thirteenth Annual West Virginia Surface Mine Drainage Task Force Symposium, Morgantown, WV. April 8-9, 1992, West Virginia Mining and Reclamation Association, Charleston, WV.

Brady, K.B.C., E.F. Perry, R.L. Beam, D.C. Bisko, M.D. Gardner and J.M. Tarantino, 1994. Evaluation of acid base accounting to predict the quality of drainage at surface coal mines in Pennsylvania, U.S.A. p. 138-147. In: International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage, Vol. 1, U.S. Bureau of Mines IC 9183, Pittsburgh, PA.
https://doi.org/10.21000/JASMR94010138

Caterpillar, 1991. Caterpillar performance handbook. 22nd Ed. Peoria, IL.

Cravotta, C.A. III, K.B.C. Brady, M.W. Smith, and R.L. Beam, 1990. Effectiveness of alkaline addition at surface mines in preventing or abating acid mine drainage: Part I. Geochemical considerations. p. 221-226. In: Proceedings: 1990 Mining and Reclamation Conference and Exhibition, April 23-26, 1990, Charleston, WV.
https://doi.org/10.21000/JASMR90010221

diPretoro, R.S. and H.W. Rauch, 1988. Use of acid-base accounts in premining prediction of acid drainage potential: a new approach from Northern West Virginia. p. 1-10. In: Proceedings: Mine Drainage and Surface Mine Reclamation, Vol. 1, U.S. Bureau of Mines IC 9183, Pittsburgh, PA.
page # is 2-10
https://doi.org/10.21000/JASMR88010002

Erickson, P.M. and R. Hedin, 1988. Evaluation of overburden analytical methods as a means to predict post-mining coal mine drainage quality. p. 11-19. In: Proceedings: Mine Drainage and Surface Mine Reclamation, Vol. 1, U.S. Bureau of Mines IC 9183, Pittsburgh, PA.
https://doi.org/10.21000/JASMR88010011

Kania, T., 1998. Laboratory methods for acid-base accounting: An update. Chapter 6. In: Coal Mine Drainage Prediction and Pollution Prevention in Pennsylvania, PA Department of Environmental Protection. Harrisburg, PA.

Perry, E., 1998. Interpretation of acid-base accounting. Chapter 11. In: Coal Mine Drainage Prediction and Pollution Prevention in Pennsylvania, PA Department of Environmental Protection. Harrisburg, PA.

Perry, E., and K. Brady. 1995. Influence of neutralization potential on surface mine drainage quality in Pennsylvania. In: Proceedings of the Sixteenth West Virginia Surface Mine Drainage Task Force Symposium, April 4-5, 1995, Morgantown, WV.

Perry, E., M. Gardner, and R. Evans, 1997. Effects of acid material handling and disposal on coal mine drainage quality. p. 1007-1026. In: Proceedings Fourth International Conference on Acid Rock Drainage, Vol. III, Vancouver, BC.

Skousen, J.G., 2000. Static tests for predicting coal mine drainage. In: Acid mine drainage prediction in the Eastern United States. Acid Drainage Technology Initiative (ADTI) Technical Report. National Mining Association and National Mine Land Reclamation Center, Morgantown, WV. Anticipated release date is April 2001.

Skousen, J., J. Renton, H. Brown, P. Evans, B. Leavitt, K. Brady, L. Cohen, and P. Ziemkiewicz, 1997. Neutralization potential of overburden samples containing siderite. J. Environmental Quality 26:673-681.
https://doi.org/10.2134/jeq1997.00472425002600030012x

Skousen, J.G., J.C. Sencindiver, and R.M. Smith, 1987. A review of procedures for surface mining and reclamation in areas with acid-producing materials. National Research Center for Coal and Energy, National Mine Land Reclamation Center. Morgantown, WV.

Skousen, J.G., R.M. Smith, and J.C. Sencindiver, 1990. Development of the acid-base account. Green Lands Vol. 20 (1): 32-37, West Virginia Mining and Reclamation Association, Charleston, WV.

Smith, M.W. and K.B.C. Brady, 1990. Evaluation of acid-base accounting data using computer spreadsheets. p. 213-219. In: Proceedings: 1990 Mining and Reclamation Conference and Exhibition, Charleston, WV.
https://doi.org/10.21000/JASMR90010213

Smith, R.M., A.A. Sobek, T. Arkle, J.C. Sencindiver, and J.R. Freeman, 1976. Extensive overburden potentials for soil and water quality. EPA-600/2-76-184. U.S. Environmental Protection Agency, Cincinnati, OH.

Sobek, A.A., J.G. Skousen, and S.E. Fisher, Jr., 2000. Chemical and physical properties of overburdens and minesoils. P. 77-104. In: Reclamation of Drastically Disturbed Lands, Agronomy No. 41, American Society of Agronomy, Madison, WI.

West Virginia Surface Mine Law, 1971. West Virginia Department of Mines. Charleston, WV.